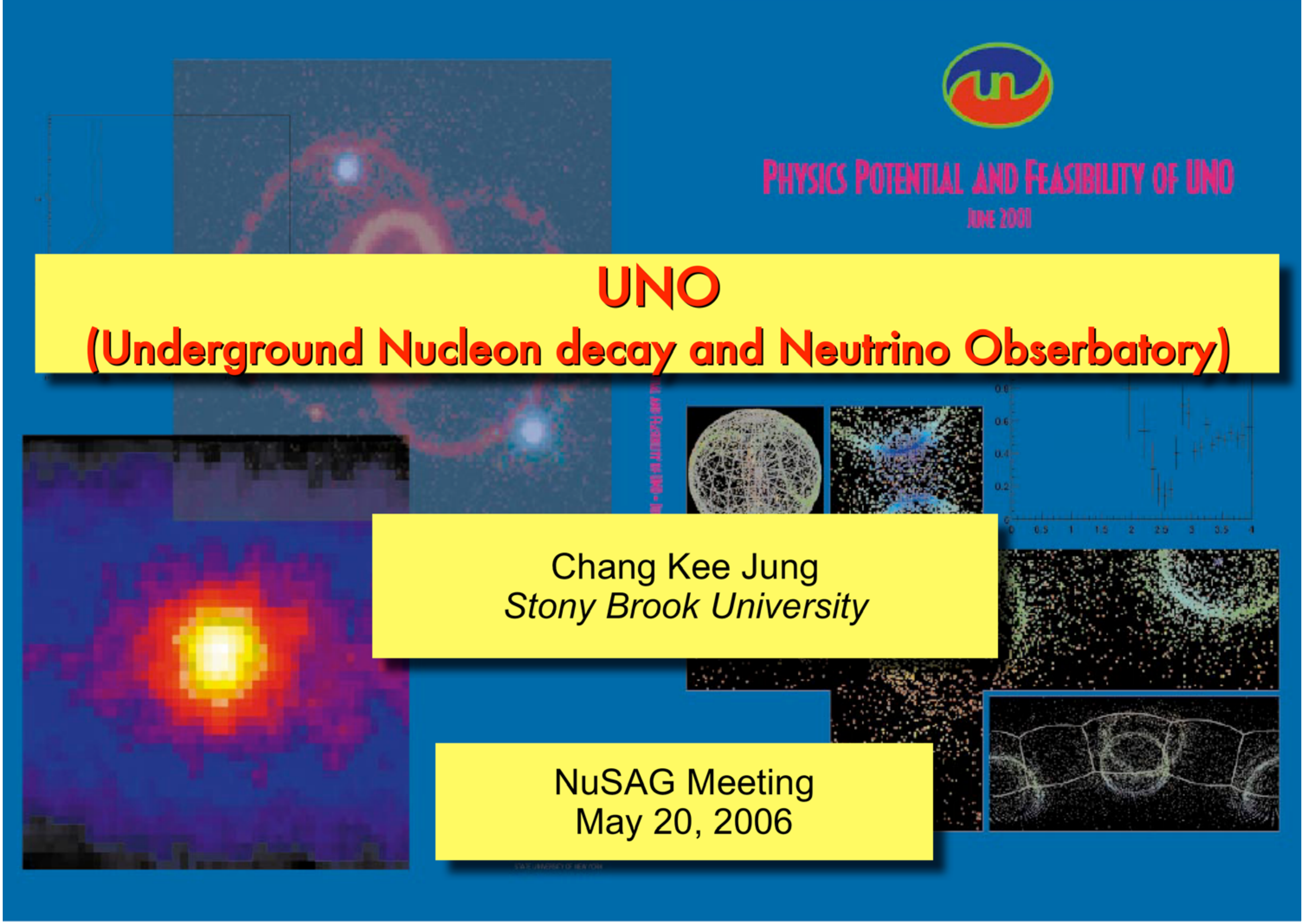
http://nngroup.physics.sunysb.edu/uno

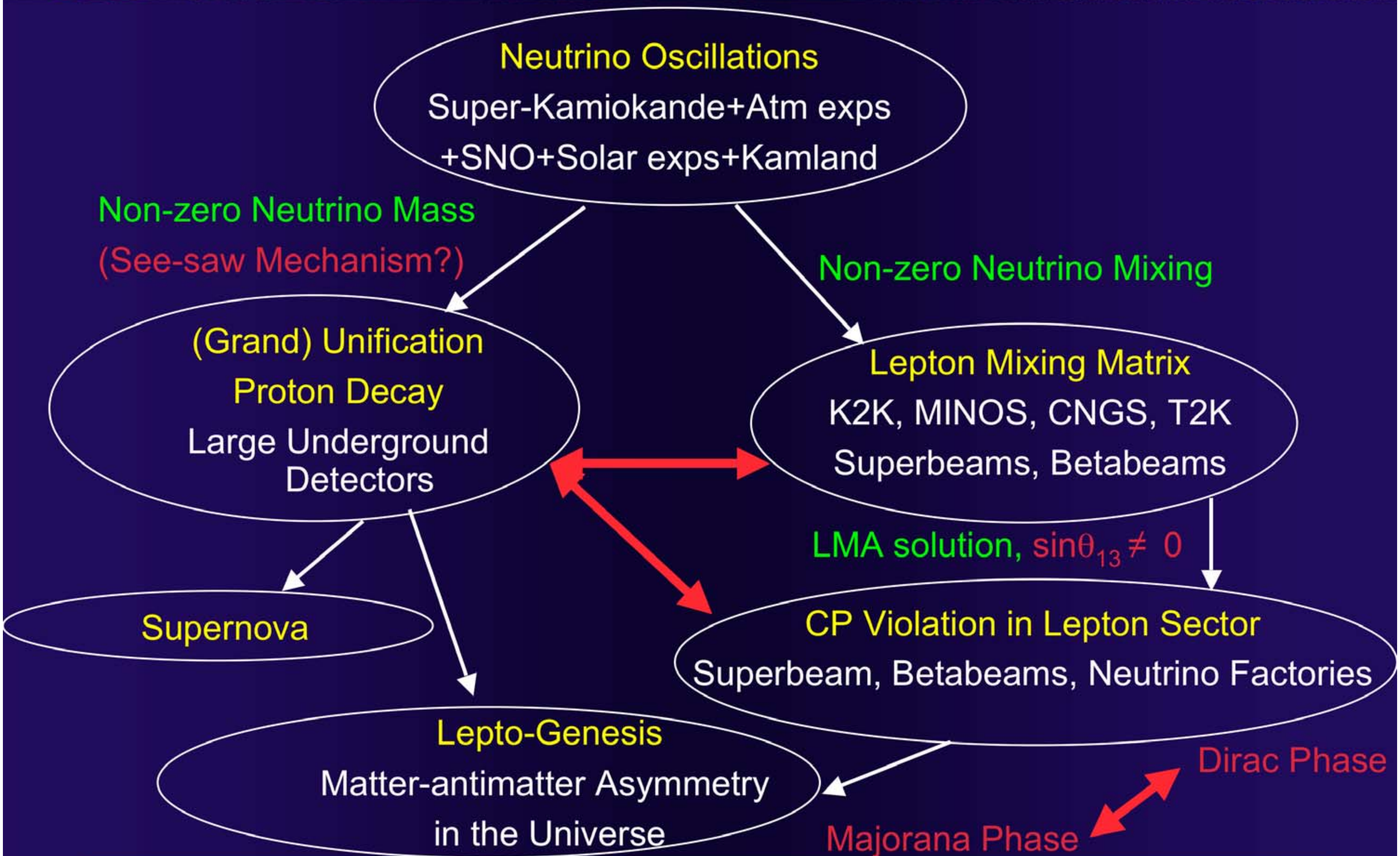


UNO
(Underground Nucleon decay and Neutrino Obserbatory)

Chang Kee Jung
Stony Brook University

NuSAG Meeting
May 20, 2006

1998 Neutrino Revolution and Physics Goals for NNN Experiments



NNN Detector Design Considerations

- Goal: physics capability ⇑ detector cost ⇓
- Topology and Size
  - Light attenuation length limit in pure water:

    ⇒ ~80 m at 400 nm
  - PMT (current Hamamatsu 20" PMT's) pressure limit:

    ⇒ ~6 atm (60 m of water)
  - Largest possible width of underground cavity:

    ⇒ ~60 m (depends highly on the local geology)

⇒ Single largest active module size: ~60m x 60m x 60m

- PMT (photocathode) coverage
  - Need relatively high coverage (~ 40%) for low energy physics (solar and SRN), and 6 MeV γ detection from $p \rightarrow K^+\nu$ in oxygen
  - Need fine granularity for LBL ν_e appearance experiments to reject π^0 background

Continue: Design Considerations

- Number and size of the modules for a fixed fiducial volume
  - Module size $\Downarrow$ detector cost $\Uparrow$
    - $\Rightarrow$ Larger surface area to fiducial volume ratio

      Requires more PMTs
    - $\Rightarrow$ Smaller fiducial to total volume ratio
    - $\Rightarrow$ Need more drifts and auxiliary/service space

      typically excavation costs for drifts are more expensive than for large volume excavation
  - Module size $\Downarrow$ Energy Containment $\Downarrow$
    - $\Rightarrow$ especially crucial in atm nu studies, such as L/E study
  - Module size $\Downarrow$ Pattern Recognition Capability (with same photocathode coverage) $\Downarrow$

$\Rightarrow$ **Keep the module size as large as possible**

Detector Site Issues

- Depth ⇑
  - cosmogenic background ⇓
  - rock instability ⇑ rock temperature ⇑ detector cost ⇑
- Optimal Depth
  - ~4000 mwe (~5000 ft)

    ⇒ Driven by the SRN search and Solar nu study

    Reduce spallation background

    ⇒ also reduce the risk of possible unknown B.G. to PDK searches at shallow depths

    ⇒ minimize detector dead time

    ⇒ keep some amount of cosmic rays for calibration purposes
- Distances from Major Proton Accelerator Labs
  - Different baselines present vastly different physics potential

Physics Beyond SuperK, T2K, NOVA

- Requires a Next generation Nucleon decay and Neutrino (NNN) detector with physics sensitivities an order of magnitude better than those of SuperK, T2K and NOVA
  - Water Cherenkov Detector: > 500 kton
  - LAr Detector: ~100 kton

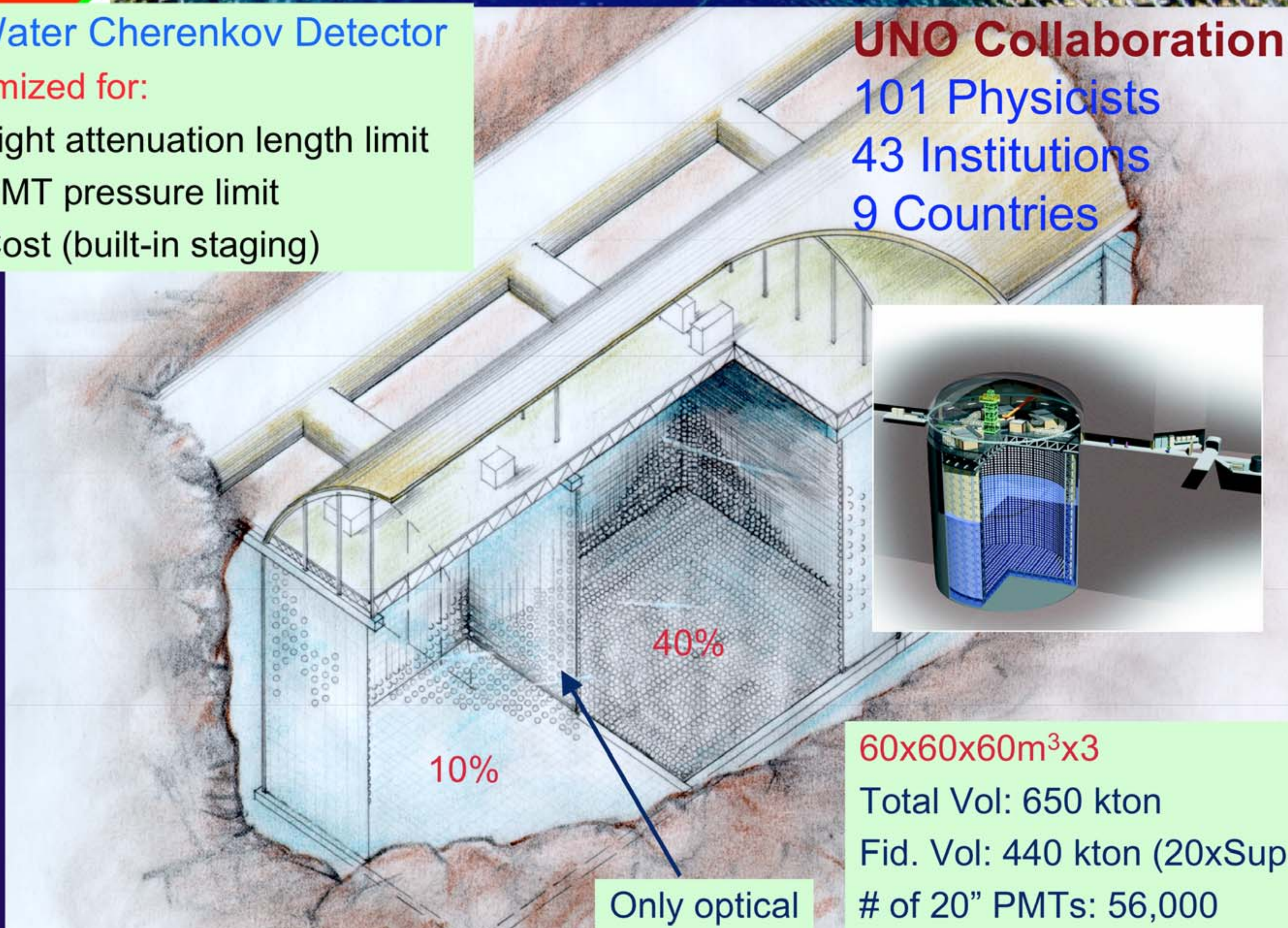
    $\Rightarrow$ a great technical challenge
  - by the time a NNN Detector is built in US, SuperK will have accumulated more than 20 years of data

UNO Detector Conceptual (Baseline) Design

A Water Cherenkov Detector
optimized for:

- Light attenuation length limit
- PMT pressure limit
- Cost (built-in staging)

UNO Collaboration
101 Physicists
43 Institutions
9 Countries



60x60x60m^{3}x3
Total Vol: 650 kton
Fid. Vol: 440 kton (20xSuperK)
# of 20” PMTs: 56,000
# of 8” PMTs: 14,900

UNO Design and NNN Workshops

- UNO first proposed in 1999 at the Next generation Nucleon decay and Neutrino Detector Workshop (NNN99)

  C. K. Jung
  "Feasibility a Next Generation Underground Water Cherenkov Detector: UNO",
  [hep-ex/0005046], NNN99 Proceedings (106 citations)

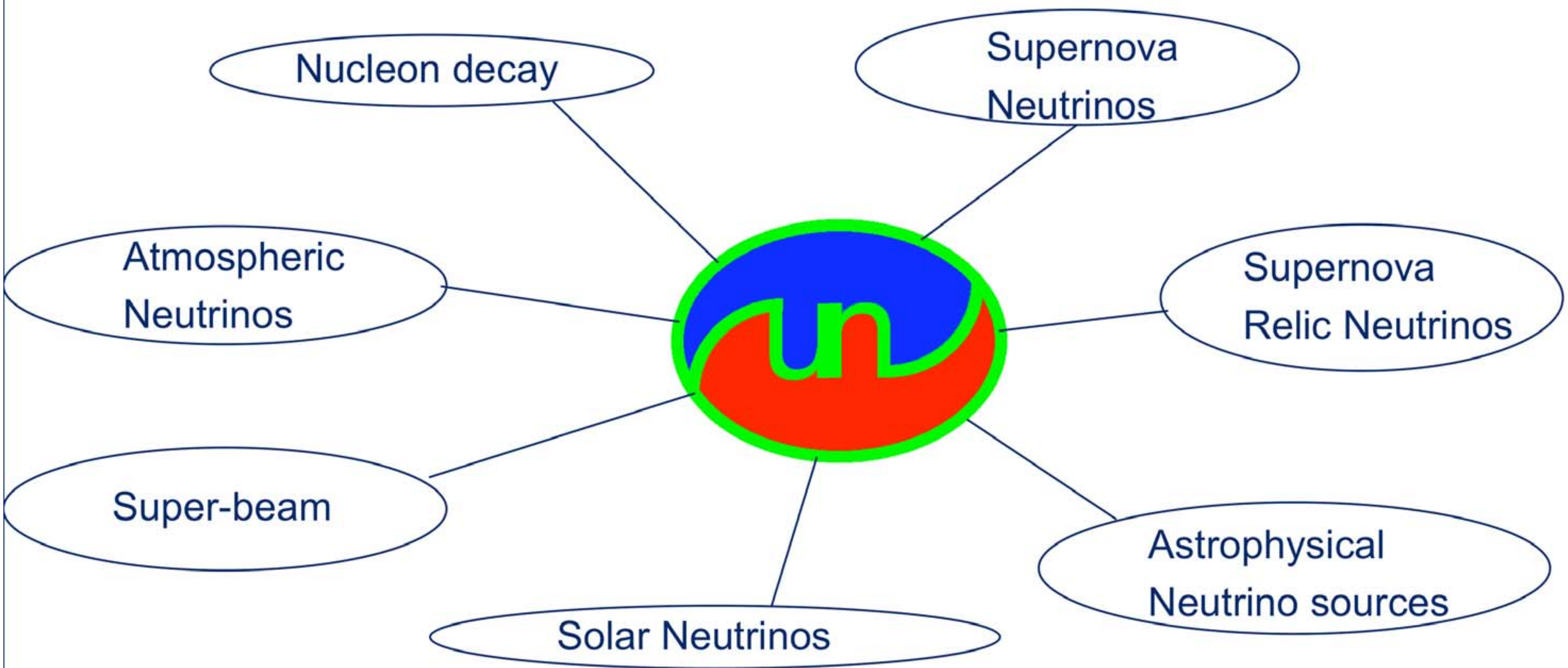
- After rigorous discussion within the UNO collaboration, the baseline design remains the same as the original
- Design optimization needed for specific detector site

  local geology can force the design to be two or three separate modules and/or narrower width

- Continuing international discussions at the NNN series workshops

  NNN05-Aussois, NNN06-Seatle, NNN07-Hamamatsu

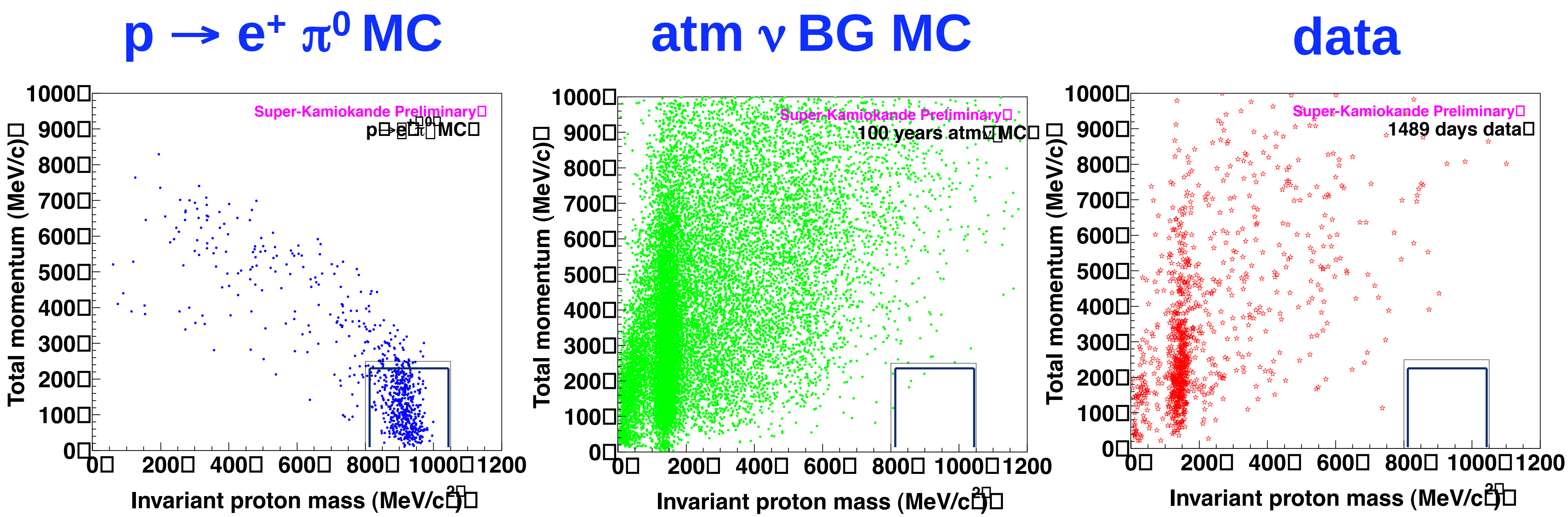
UNO Physics Goals



⇒ **Multi-purpose detector with comprehensive physics programs for astrophysics, nuclear physics and particle physics**

⇒ **Synergy between accelerator physics and non-accelerator physics**

$p \to e^+ \pi^0$ search in SuperK



41% Signal efficiency

0.3 expected Background

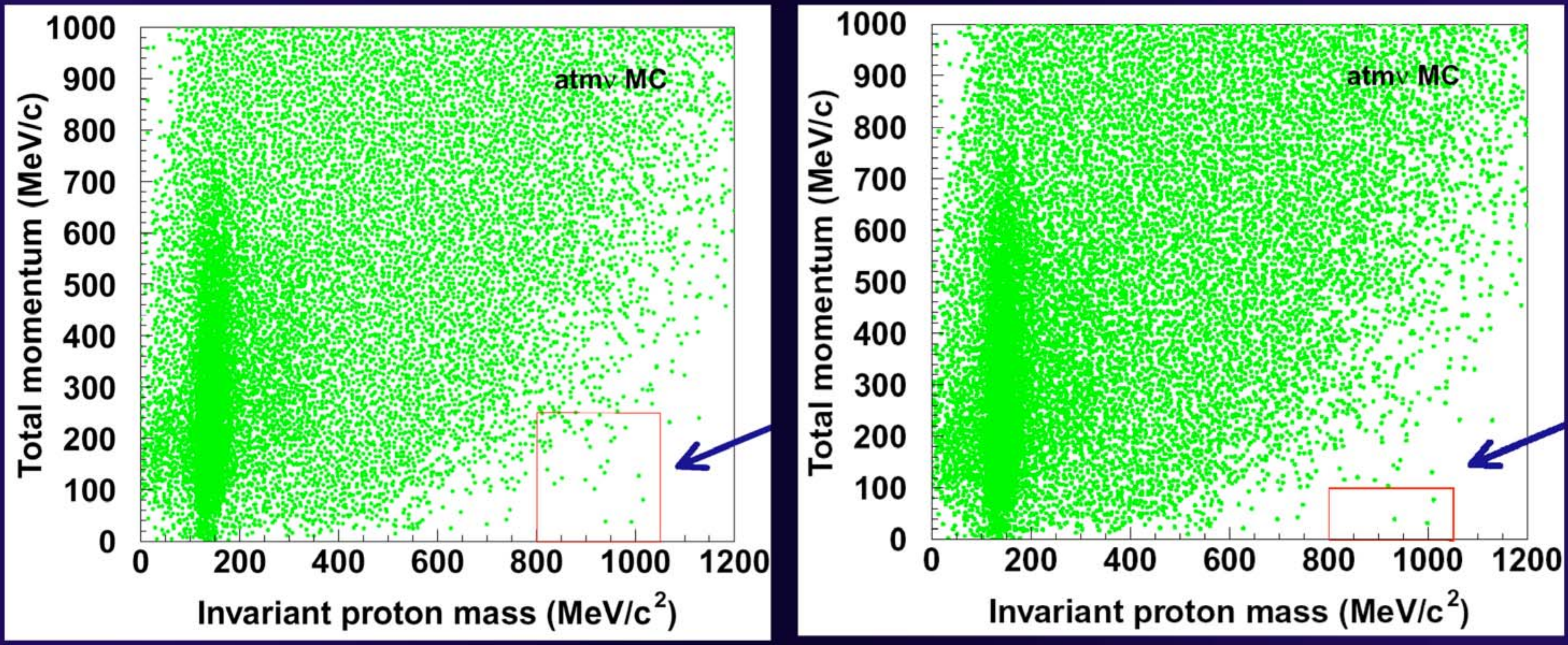
0 candidate in Data

$\tau/B(p \to e^+\pi^0) > 5.4 \times 10^{33}$ years (90%CL, w/ SK-I 1489 days data)

$\tau/B(p \to e^+\pi^0) > 1.5 \times 10^{33}$ years (90%CL, w/ SK-II 421 days data)

p –> e$^+$ π^0 Search Background

20 Mton-yr Atm nu Background MC

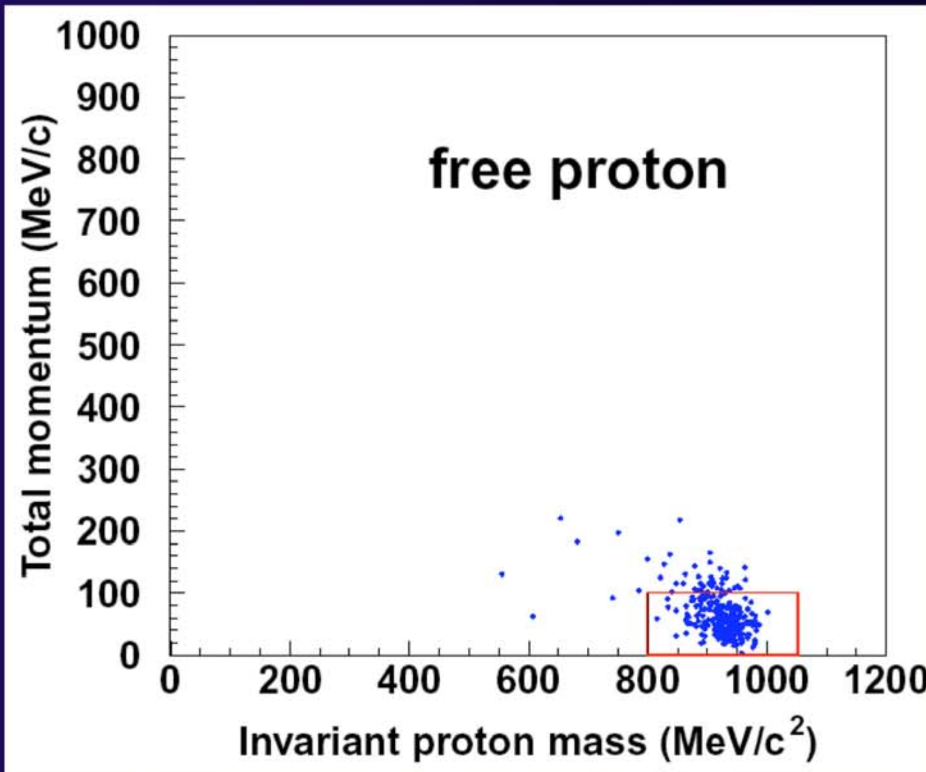


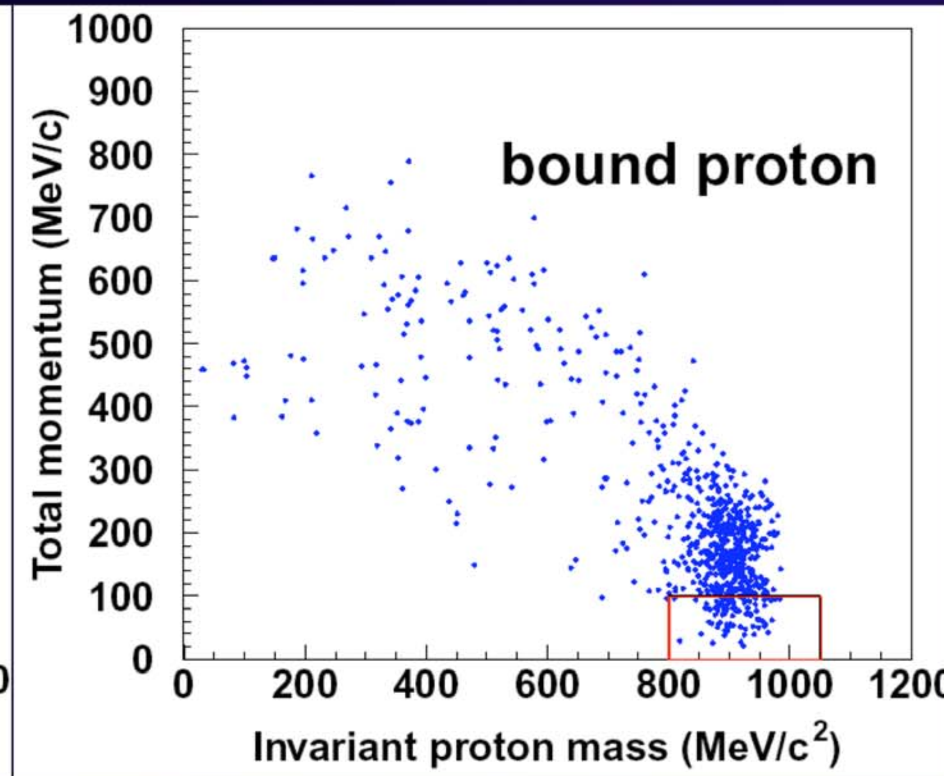
SuperK Standard Cuts
==> 2.2 events/Mton-yr
==> signal eff.: 43.0%

Tighter Momentum Cut
==> 0.15 events/Mton-yr
==> signal eff.: 17.4%

p –> $e^+ \pi^0$ Search Signal

Signal Events w/ Tighter Momentum Cut





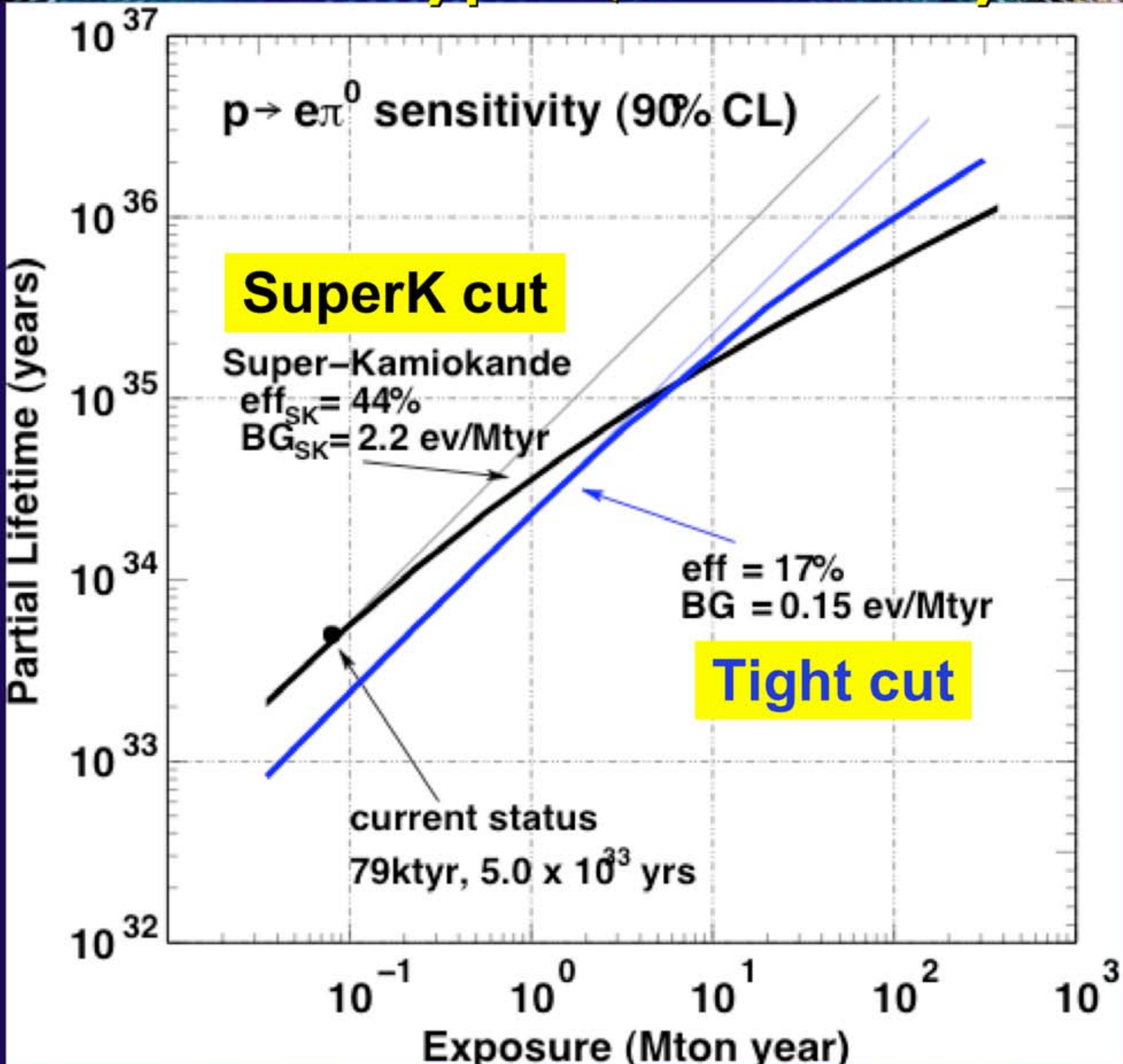
No Fermi Momentum

No Binding energy

No Nuclear effect (π^0 scattering, absorption and charge exchange)

⇒ Important to have a medium with free protons

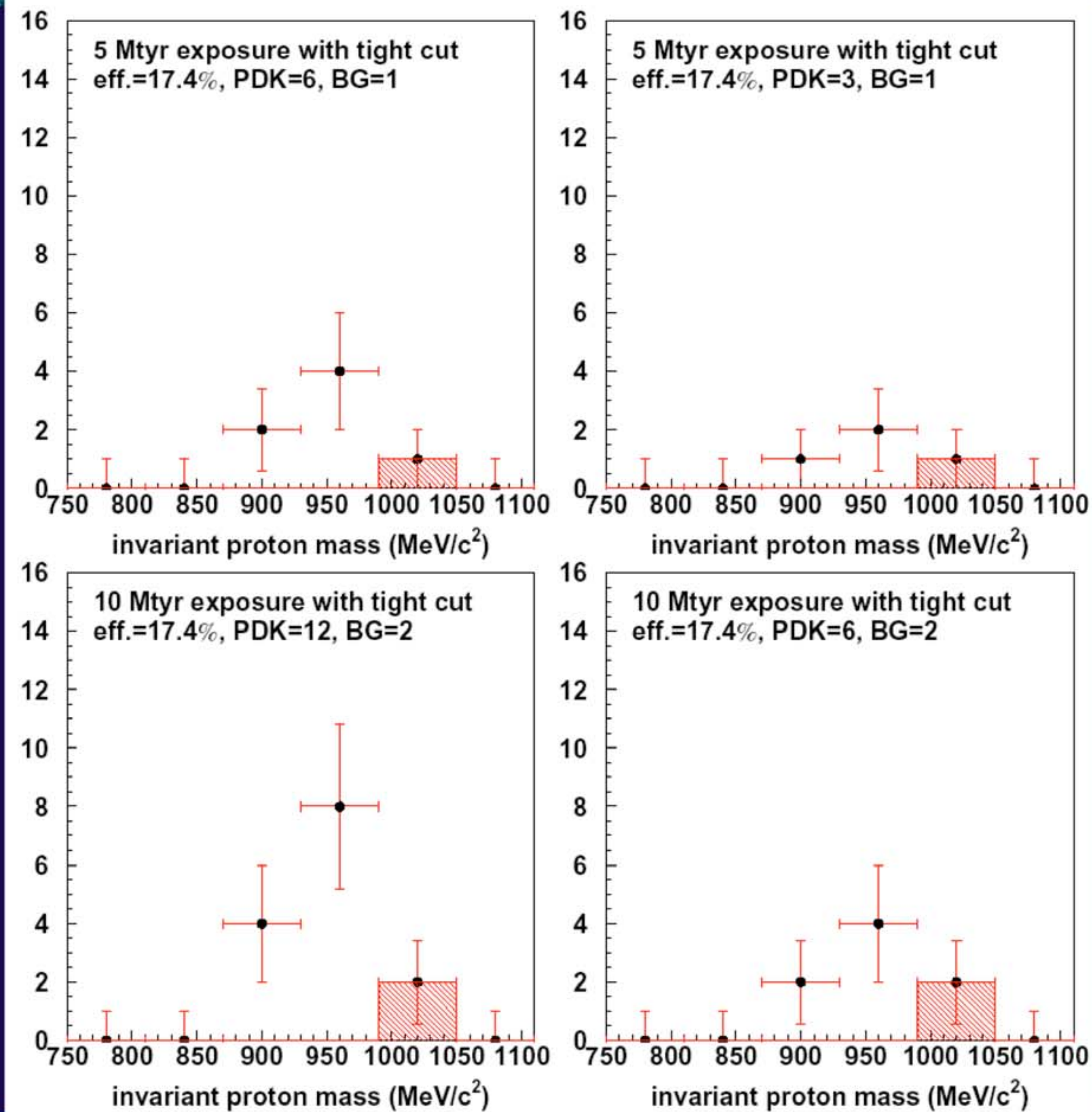
Comparison of the Standard SuperK Analysis and the HyperK/UNO Analysis



Room to Improve…

Reconstructed Mass Peak from $p \to e^+ \pi^0$

$\tau/B(p \to e^+ \pi^0)$
$= 5 \times 10^{34}$ years
1 candidate
event/~1.5 yrs



$\tau/B(p \to e^+ \pi^0)$
$= 1 \times 10^{35}$ years
1 candidate
event/~3 yrs

UNO-Keystone Unification Day Workshop
Speakers List

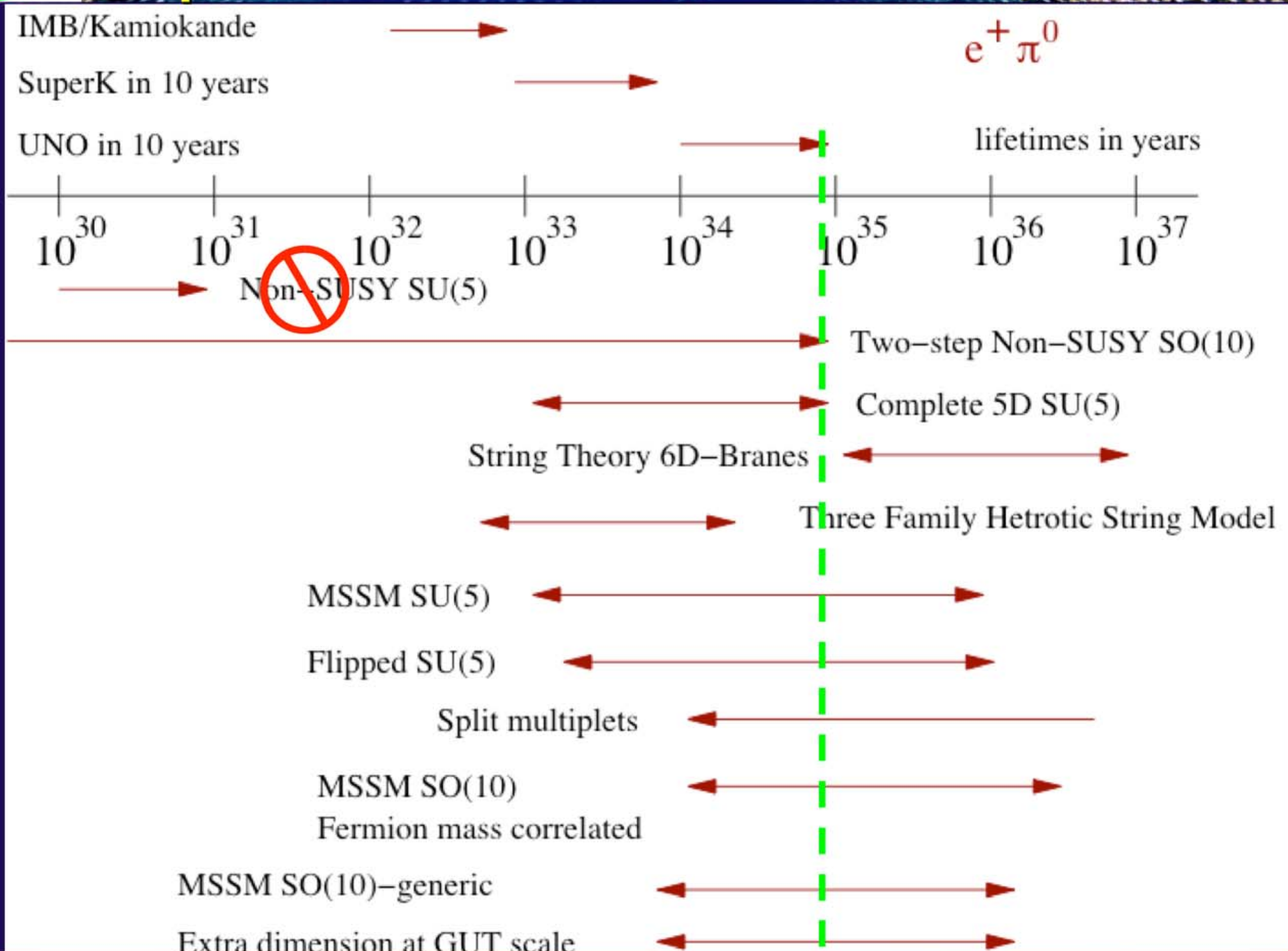
Name	Institution
E. Witten	IAS
Juan Maldacena	Harvard
Savas Dimopoulos	Stanford
Stuart Raby	Ohio State
Daniel Larson	Berkeley
Bill Marciano	BNL
Qaisar Shafi	Bartol Inst.
Rabi Mohapatra	Maryland
J. Pati	Maryland
Kaladi Babu	Oklahoma State
Yasunori Nomura	Berkeley
Keith Dienes	Arizona
Ilia Gogoladze	Notre Dame
Goran Senjanovic	ICTP, Trieste

October, 2004

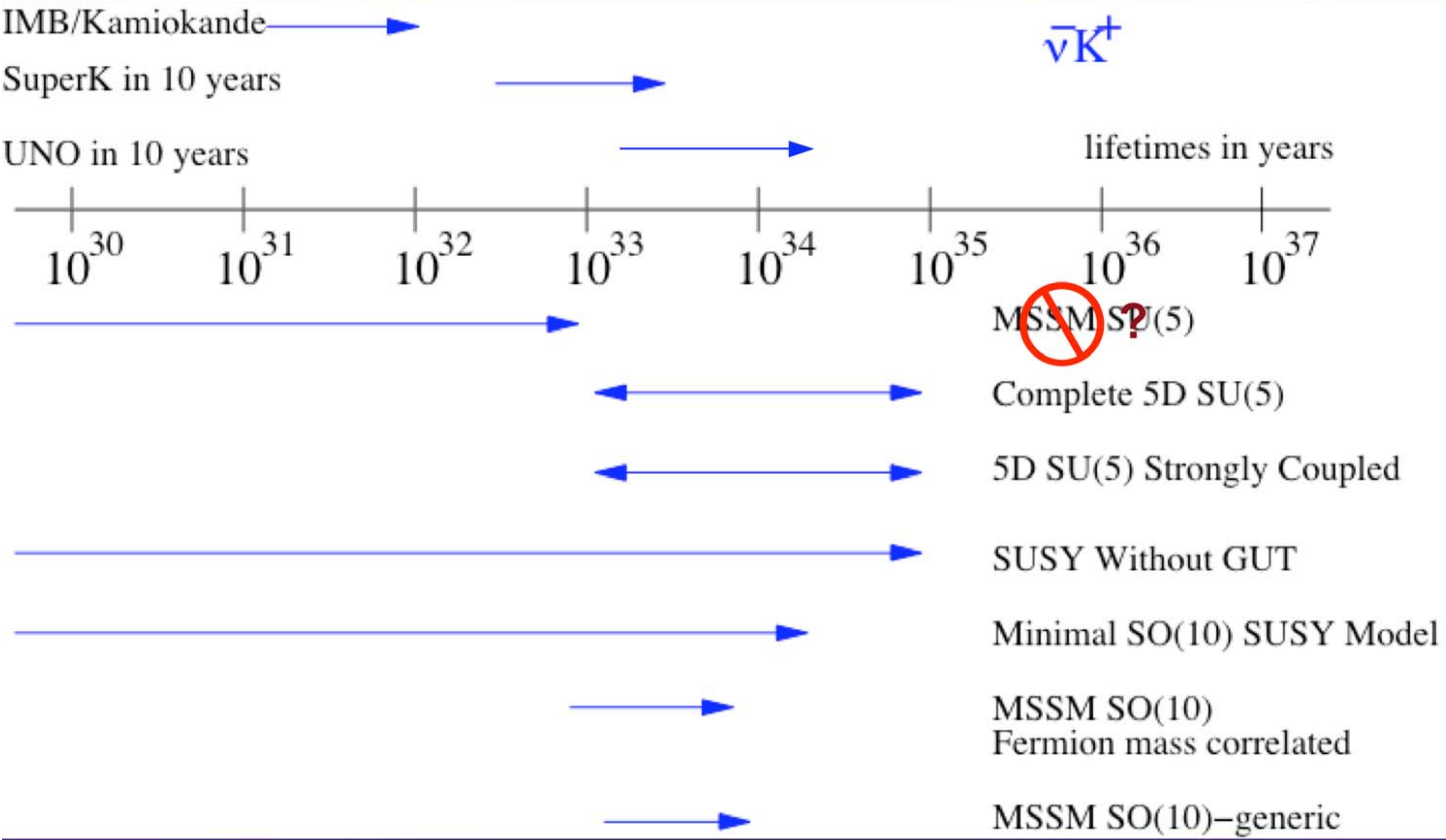
Keystone,Colorado

Co-organized by
Witten and Jung

UNO Proton Decay Sensitivity and Updated Theoretical Predictions ($e^+\pi^0$)



UNO Proton Decay Sensitivity and Updated Theoretical Predictions ($K^+\nu$)

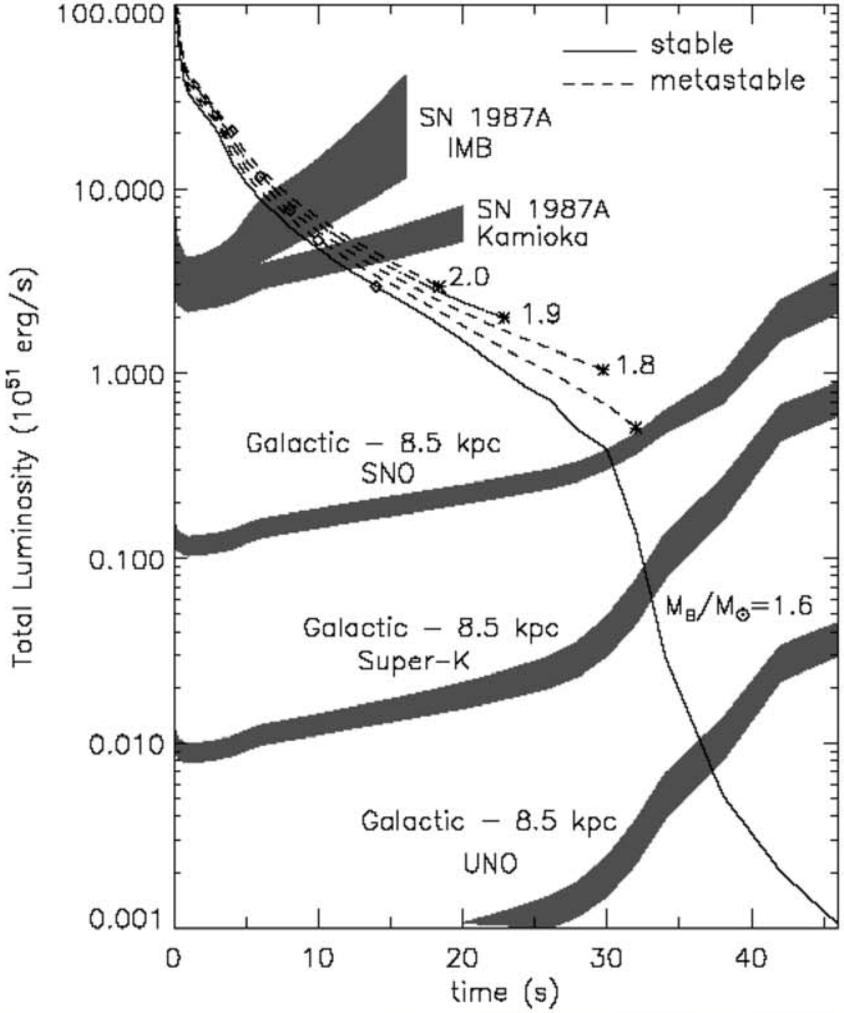


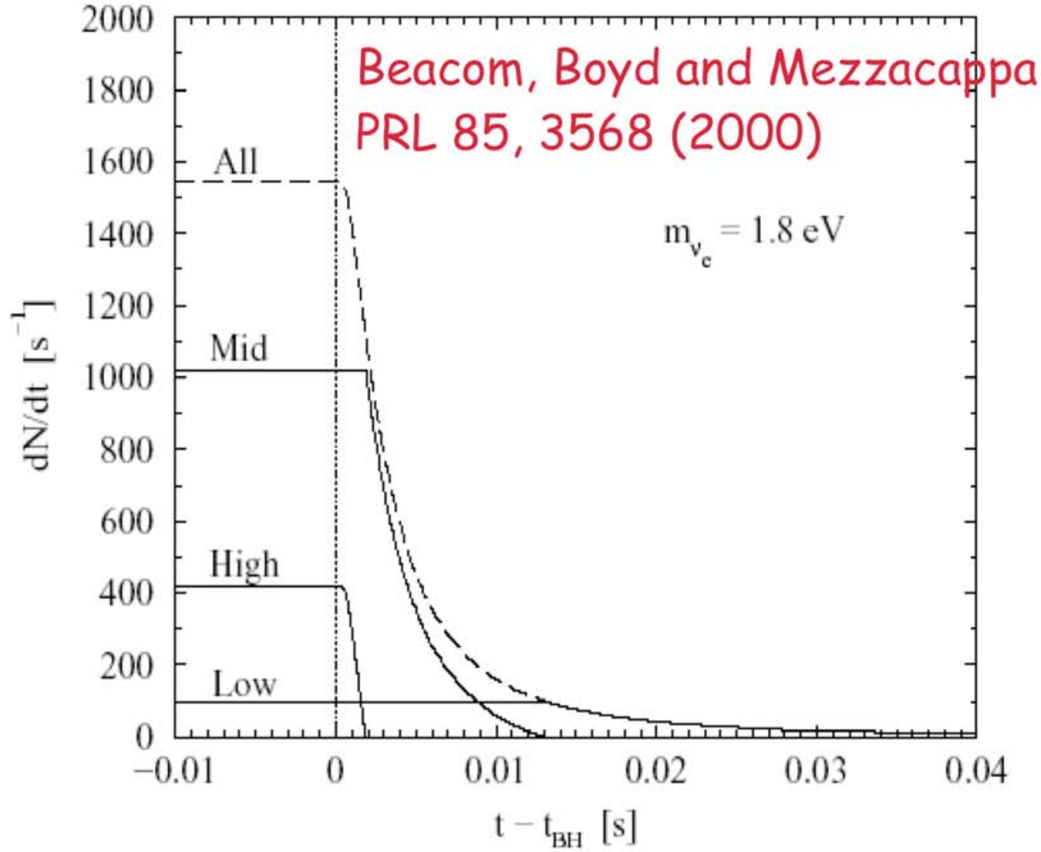
Andromeda Galaxy

Supernova Reach ~ 1 Mpc (local group of galaxies)

Supernova Rate ~ 1/10 or 15 yrs

Galactic Supernova





~140,000 events in UNO, ~1/30 years

⇒ msec timing structure of the flux ⇒

An example of unstable Eq. Of State

Pons et al., PRL 86, 5223 (2001)

⇒ Determination of core collapse mechanism

⇒ Possible Observation of Birth of a Black Hole!

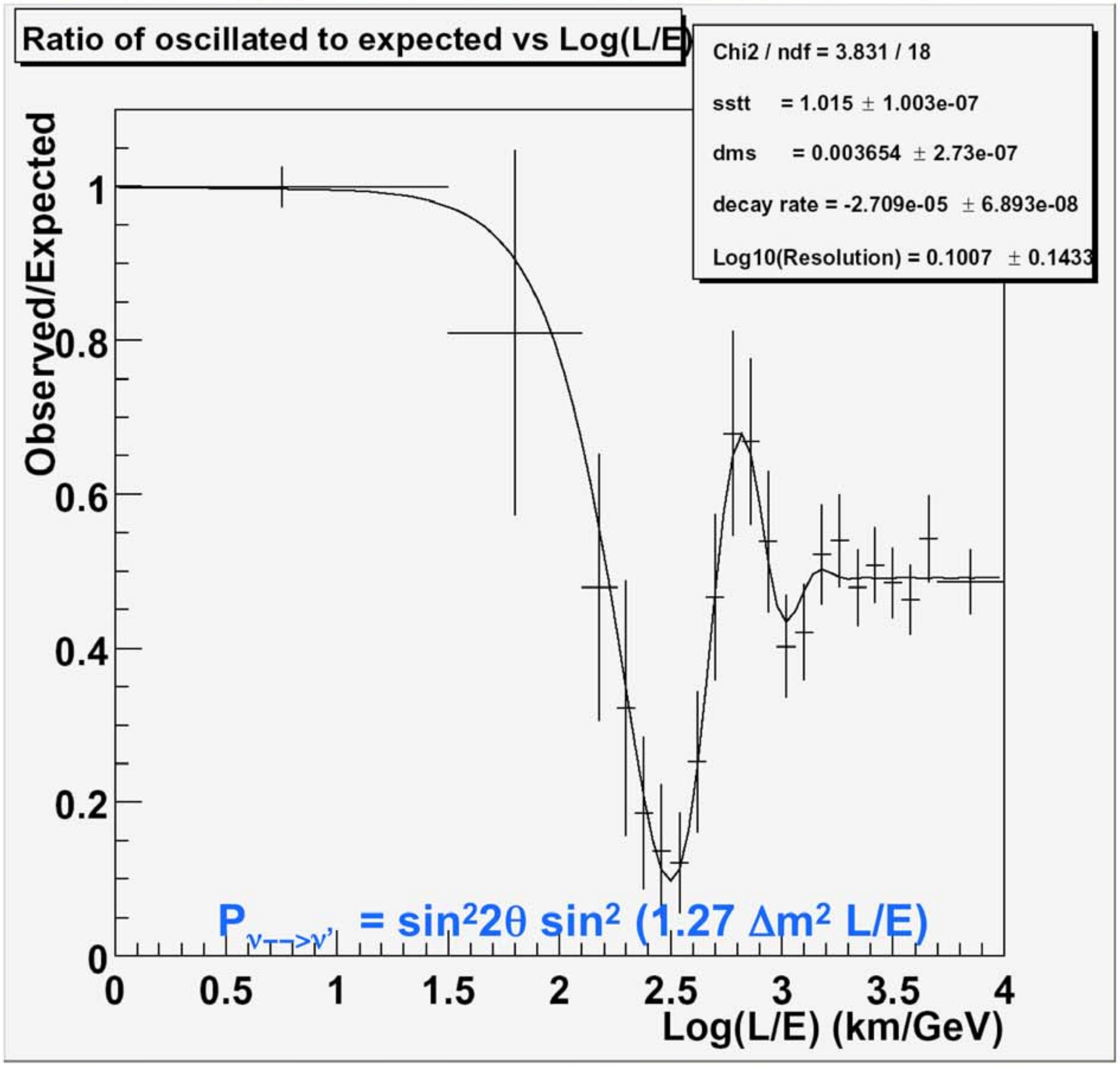
SuperK SNR ν Search Limits

Theory Model	SK SRN Rate Limit (Efficiency Corrected)	SK SRN Flux Limit (18 MeV < Ee < 82 MeV)	SK SRN Flux Limit (Full Spectrum)	Predicted SRN Flux (Full Spectrum)
Galaxy evolution (Totani et al., 1996)	$3.2 \frac{\text{events}}{\text{year } 22.5 \text{ kton}}$	$< 1.2 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$< 130 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$44 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$
Heavy metal abundance (Kaplinghat et al.,2000)	$3.0 \frac{\text{events}}{\text{year } 22.5 \text{ kton}}$	$< 1.2 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$< 29 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$< 54 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$
Constant supernova rate (Totani et al., 1996)	$3.4 \frac{\text{events}}{\text{year } 22.5 \text{ kton}}$	$< 1.2 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$< 20 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$52 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$
LMA neutrino oscillation (Ando et al., 2002)	$3.5 \frac{\text{events}}{\text{year } 22.5 \text{ kton}}$	$< 1.2 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$< 31 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$	$11 \frac{\overline{\nu_e}}{\text{cm}^2 \text{ sec}}$

M.S. Malek et. al, Phys. Rev. Lett. 90, E-ID 061101 (2003)

UNO at 4000 mwe can rule out all models within six years or discover SNR

Direct Observation of Oscillatory Behavior in L/E



$P_{\nu_\tau \to \nu'} = \sin^2 2\theta \sin^2 (1.27\, \Delta m^2\, L/E)$

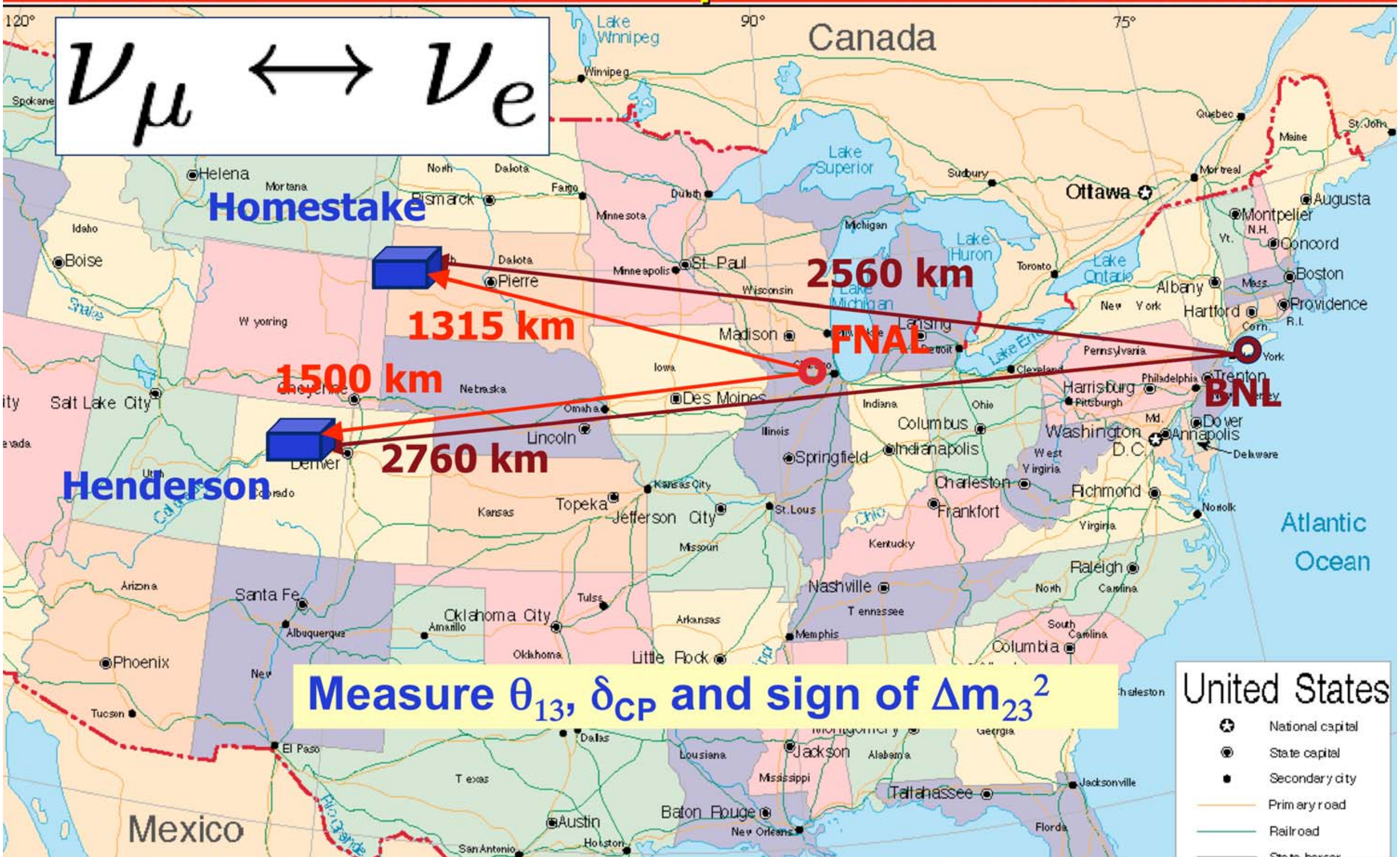
~7 years of UNO exposure

($\Delta m^2 = 0.003\ eV^2$, $\sin^2 2\theta = 1.0$)

- 1 muon w/ E > 1GeV or
- $E_{vis}\ (\mu) > 0.5\ E_{vis}$ (total)
- removal of horizontal events

Very Long Baseline Neutrino Oscillation Experiment

$$\nu_\mu \leftrightarrow \nu_e$$



Measure θ_{13}, δ_{CP} and sign of Δm_{23}^2

UNO-TAC

- UNO-TAC (Theoretical Advisory Committee)
  - John Bahcall (IAS/Princeton), Deceased
  - John Beacom (FNAL)
  - Adam Burrows (U. of Arizona)
  - Maria Concepcion Gonzales-Garcia (Stony Brook)
  - Jim Lattimer (Stony Brook)
  - Cecilia Lunardini (U. of Washington)
  - Bill Marciano (BNL)
  - Hitoshi Murayama (Berkeley)
  - Jogesh Pati (U. of Maryland)
  - Robert Shrock (Stony Brook)
  - Frank Wilczek (MIT)
  - Edward Witten (IAS/Princeton)

UNO-AC

- UNO-AC (Advisory Committee)
  - Gene Beier (U. Penn)
  - Alesandro Bettini (U. of Padoa)
  - Jacque Bouchez (Saclay)
  - Charles Fairhurst (U. of Minnesota)
  - Maury Goodman (ANL)
  - Tom Kirk (BNL)
  - Takahaki Kajita (ICRR)
  - Tony Mann (Tufts)
  - Kenzo Nakamura (KEK)
  - Masayuki Nakahata (ICRR)
  - Yoichiro Suzuki (ICRR)
  - Jeff Wilkes (U. of Washington)
  - Bob Wilson (Colorado State U.)

UNO R&D Activities and Proposal

Technical Feasibility and Reasonable Cost

- Is it feasible to excavate a UNO size cavern?
  - Can it be stable for > 30 years?
  - Can it be done economically?
- Can the water containment be done using liners?
  - Can it be stable for > 30 years?
  - Can it be done economically?
- Can the PMT mounting system be built economically?
- Can the photo-detection be done more economically?
  - Cheaper PMTs?
  - New photo-detectors?

$\Rightarrow$ UNO R&D Proposal

UNO EOI and R&D Proposal

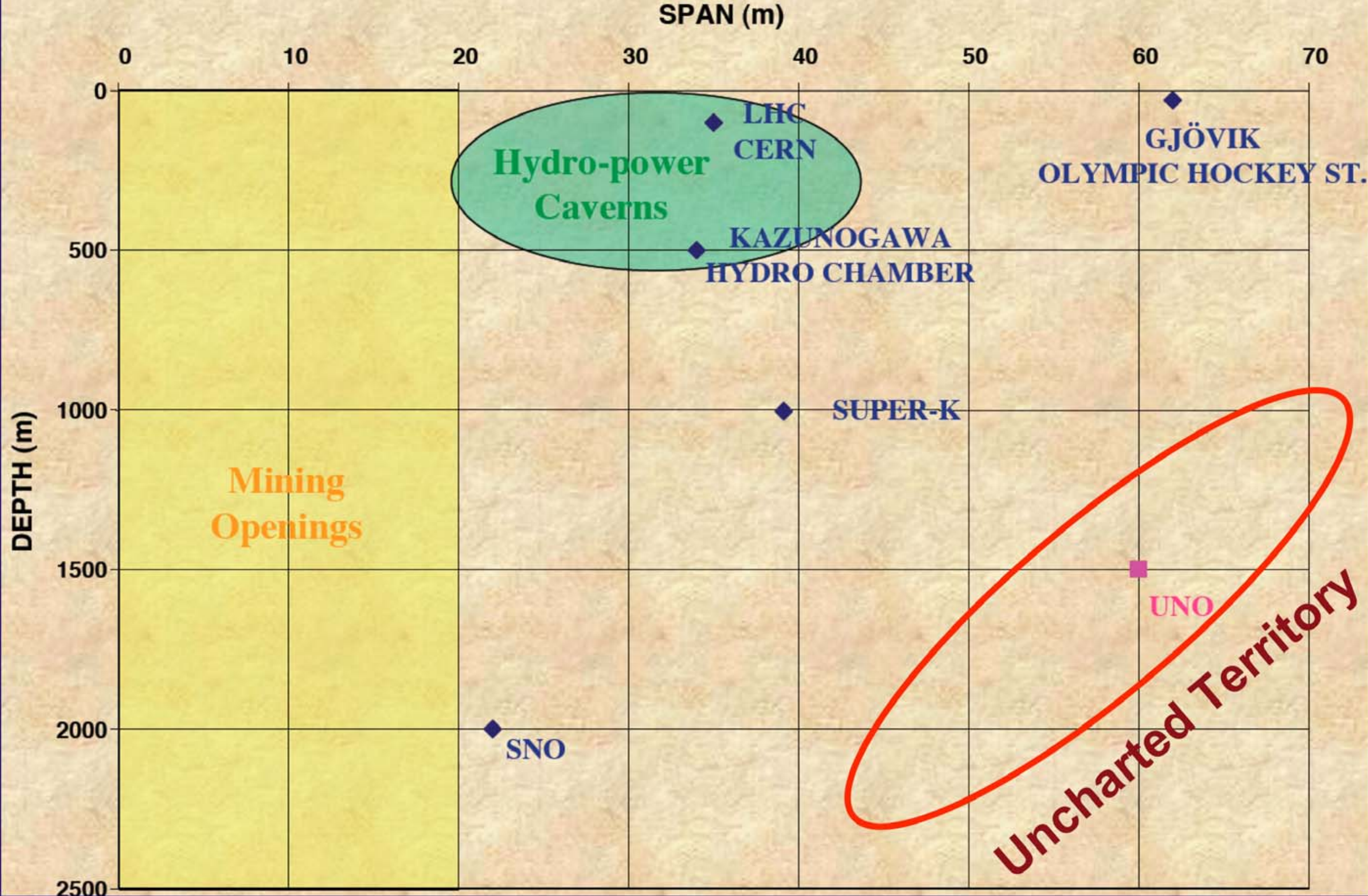
- Proposed Planning and R&D Activities
  - Excavation R&D (CSM/CNA Engineers/Itaska)
  - Cavity Liner R&D (CSM/CSU)
  - PMT Mounting R&D (UW)
  - Photo-detector R&D
    - ⇒ PMT Testing (Stony Brook/CSU)
    - ⇒ Referenc Tube R&D, already funded (UC-Davis)

      DOE Advanced Detector R&D and DOE (~$600k)
    - ⇒ Burle Large PMT R&D, already funded (DOE SBIR)
    - ⇒ (U. of Tokyo HPD R&D, already funded ($4M))
  - UNO software R&D (BNL/CSU/Stony Brook)
  - Planning (Stony Brook)

How big a cavern can we construct underground?
A challenge to the mining engineering community

Possible application in the future:
Large underground facility/storage
Large underground living space

Bench Marking
(P. Varona, Itasca)



Norwegian Hockey Arena
Gjøvik, Norway

Dimensions: L=91m, W=61m, H=25m, Ar=15,000m^2

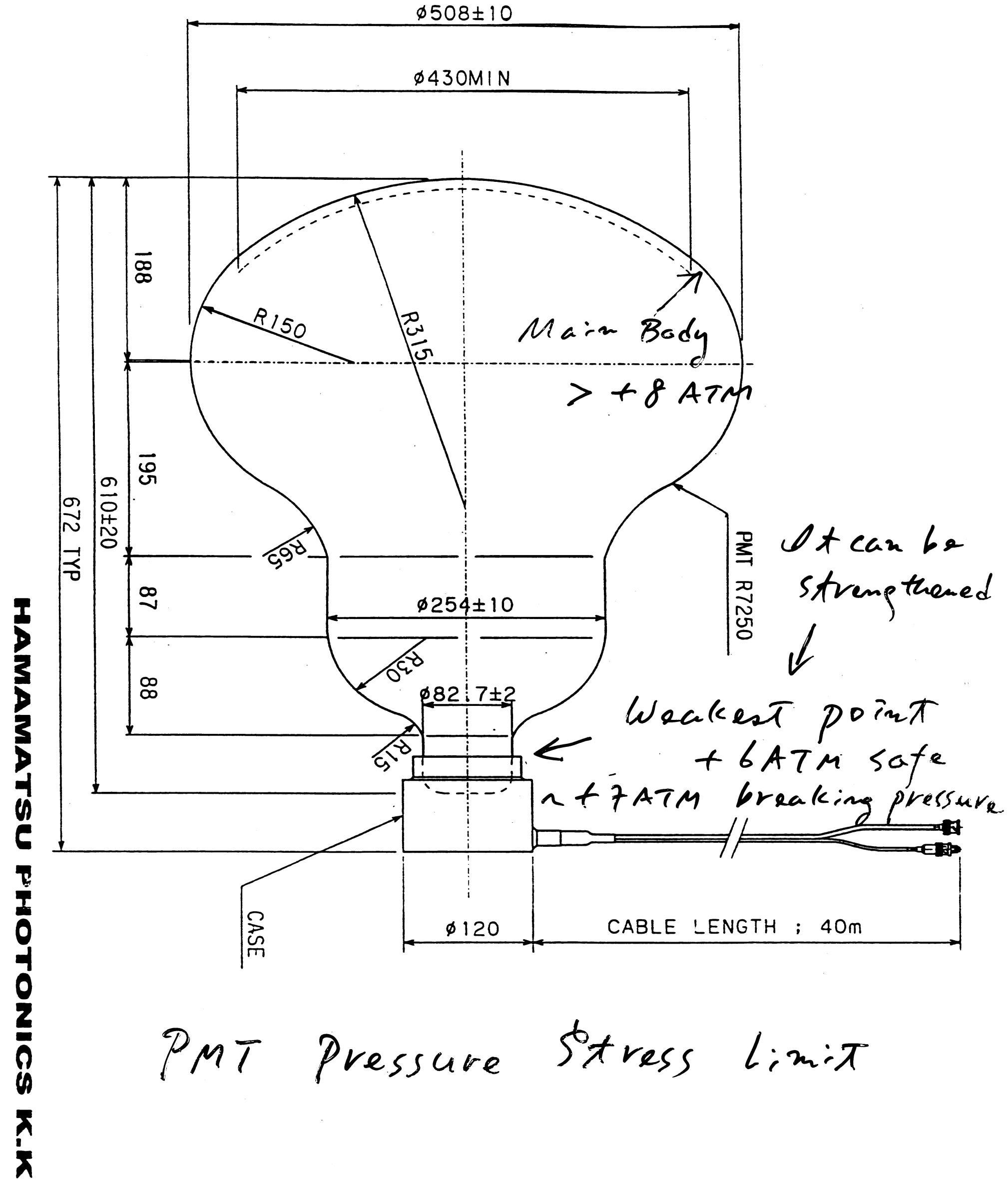
Construction Cost: $20M USD (1992)

Good Luck Cave
Sarawak, Borneo

Gunung Mulu National Park, a Karst cave (limestone)

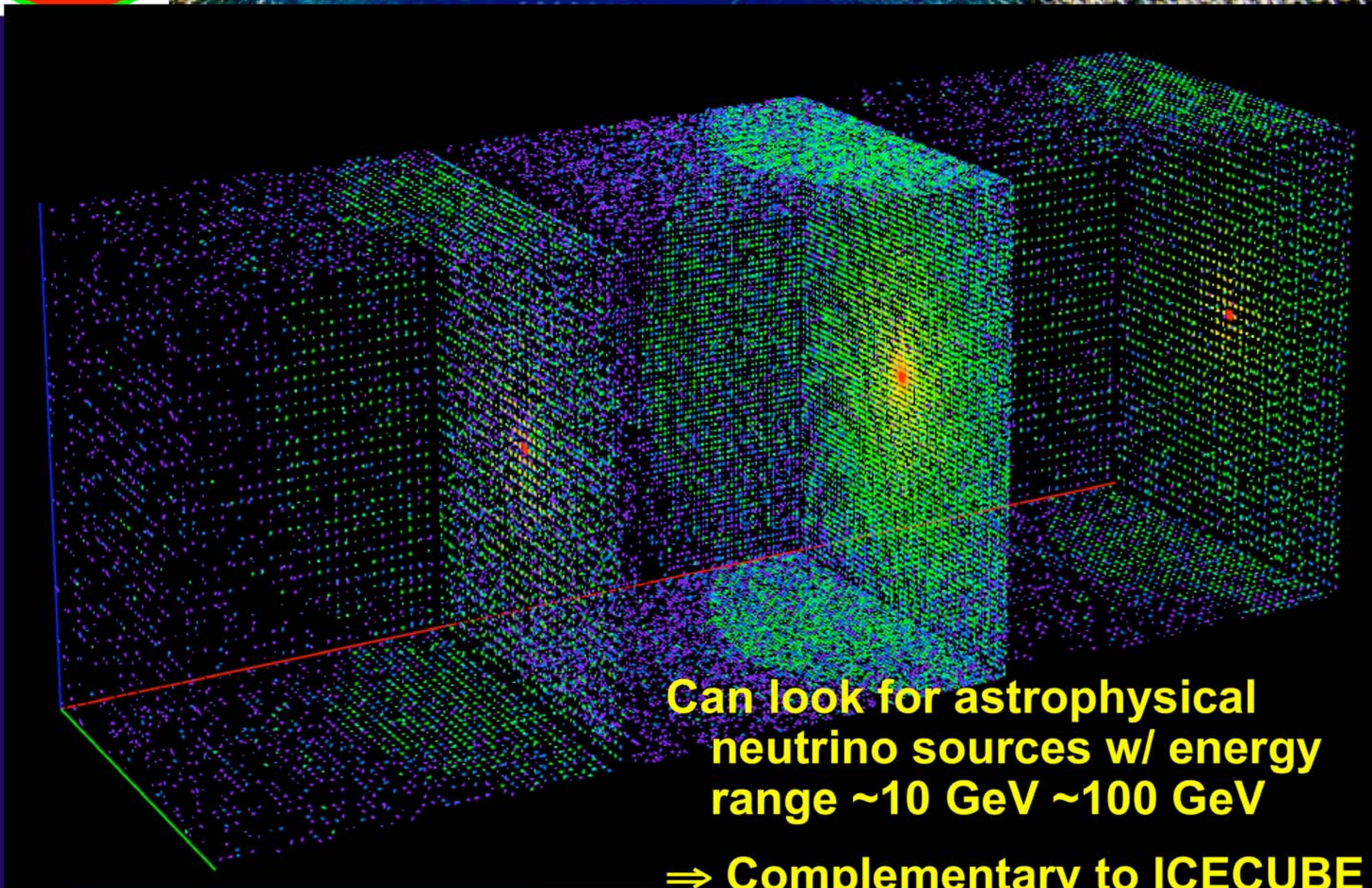
Dimensions: L=600m, W=400m, H=100m, Ar=162,700m^2

Hamamatsu 20" PMT Pressure Stress Limit



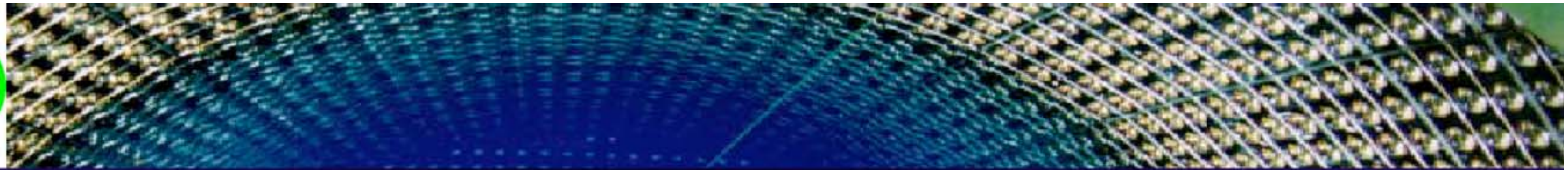
===> Spherical PMT and other photo-detector R&D

Through-going Muon Event in UNO



Can look for astrophysical neutrino sources w/ energy range ~10 GeV ~100 GeV

⇒ Complementary to ICECUBE



Background (Pi-zero) Study for VLBNO Experiment

Can a Large Water Cherenkov Detector be Used for a Superbeam Experiment?

Chiaki Yanagisawa and the SBU NN group

Stony Brook University

Analysis Tools and Setup

- Use of SK atmospheric neutrino MC (40% photo-cathode coverage)
  - Standard SK analysis package + special π^0 finder
  - Flatten SK atm. ν spectra and reweight with BNL beam spectra
  - Normalize with QE events: 12,000 events for ν_μ , 84 events for beam ν_e for 0.5 Mt F.V. with 5 years of running, 2,540 (1,480) km baseline

2500 kt• MW•10^7 sec
BNL 30 GeV AGS

distance from BNL to Homestake
(distance from Fermilab to Henderson)

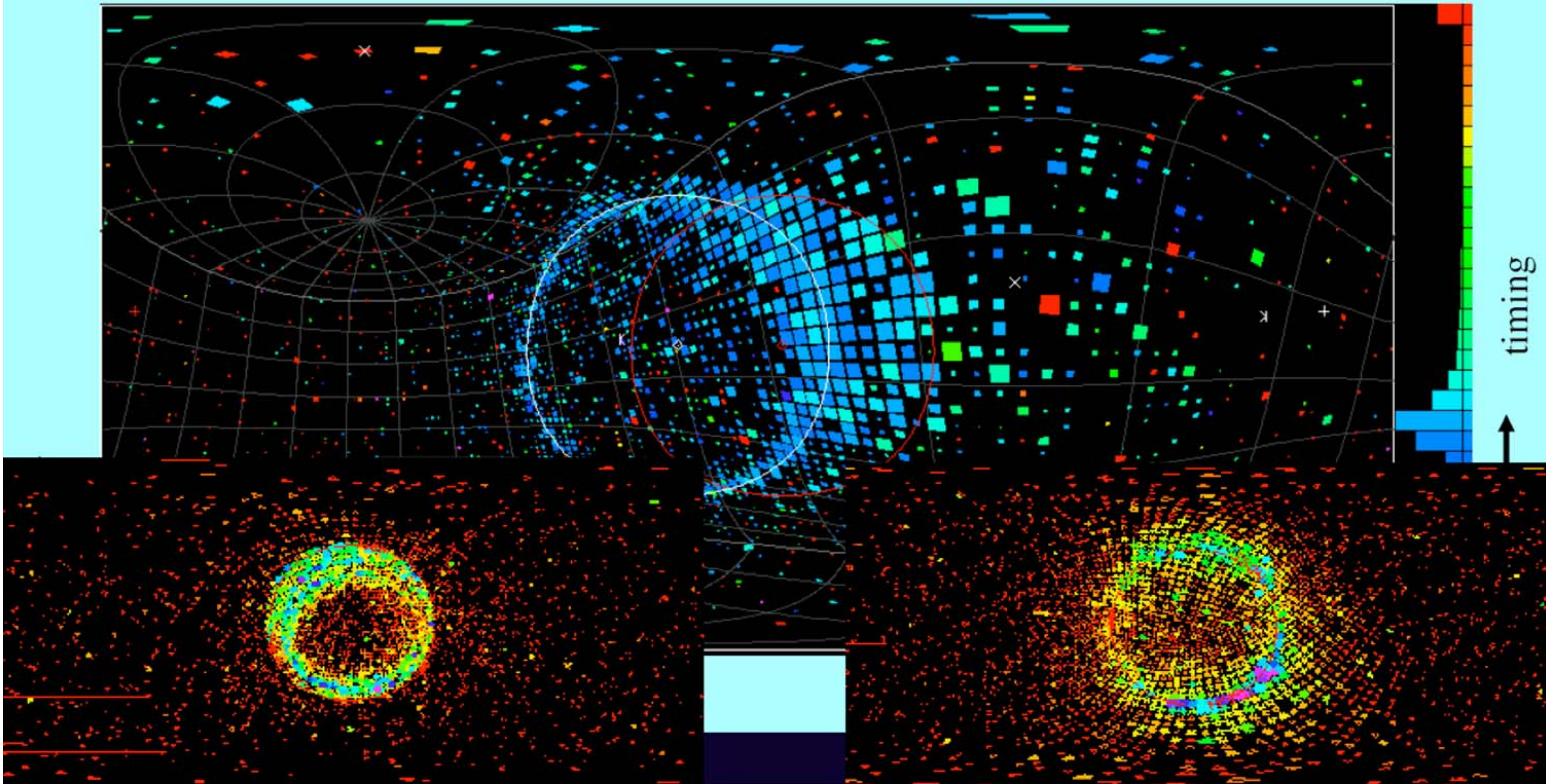
  - Reweight with oscillation probabilities for ν_μ and for ν_e

- Oscillation parameters used:
  - **Δm^2_{21} =7.3 x 10^{-5} eV^2, Δm^2_{31}=2.5 x 10^{-3}eV^2**
  - **$\sin^2 2\theta_{ij}$(12,23,13)=0.86/1.0/0.04, δ_{CP}=0,+45,+135,-45,-135^o**

Probability tables from Brett Viren of BNL

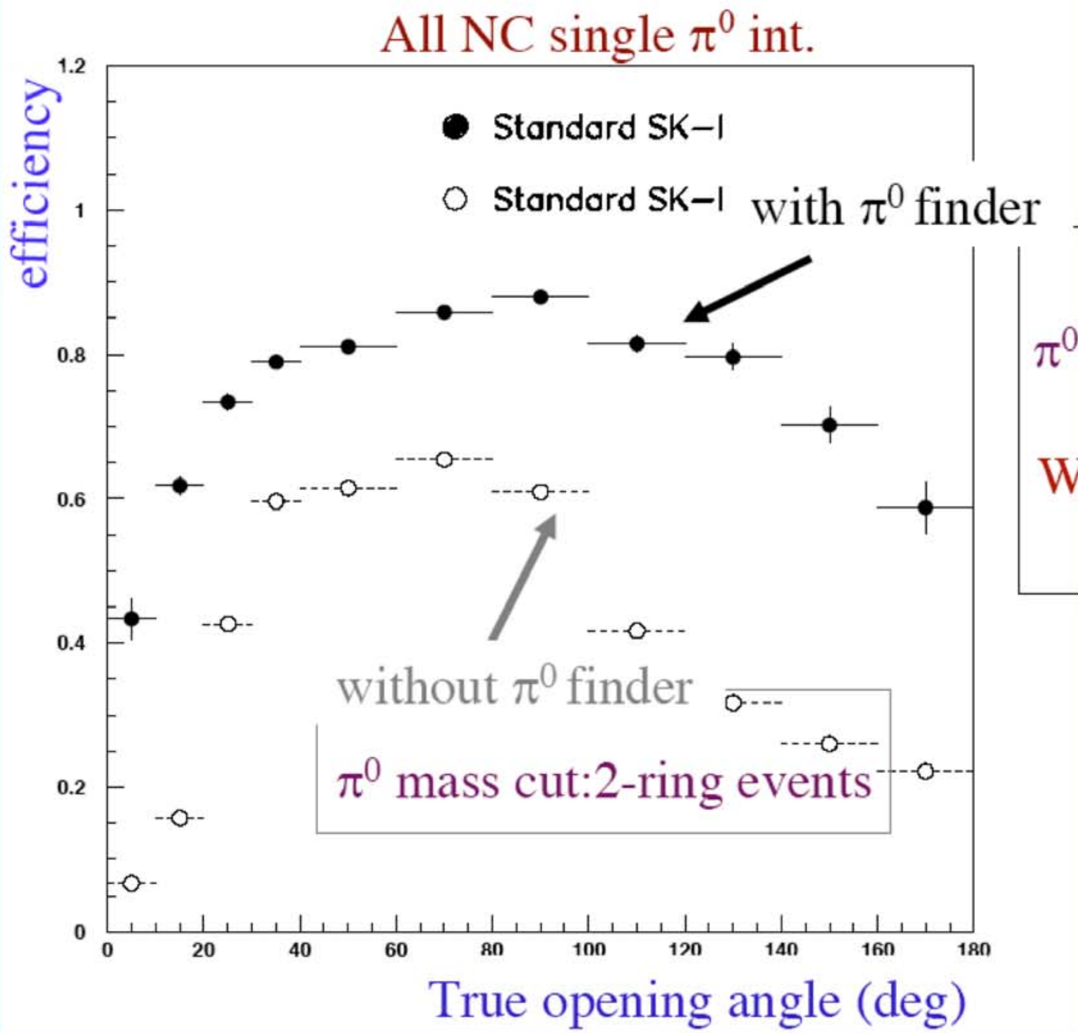
Example: K2K π^0 Event in SuperK

- What a π^0 event look like?
  A real K2K event detected by SK with two e-like rings identified as a single π^0 using a special π^0 finder



π^0 Finder Efficiency

- π^0 "reconstruction efficiency" with standard SK + π^0 finder



with π^0 finder

w/o π^0 finder

π^0 mass cut:1- and 2-ring events

With atmospheric neutrino spectra

Selection Criteria

- Initial cuts: Traditional SK cuts only
  - One and only one electron-like ring with energy and reconstructed neutrino energy more than 100 MeV without any decay electron

$$E_\nu^{rec} = \frac{m_N E_e}{m_N - (1 - \cos\theta_e) E_e}$$

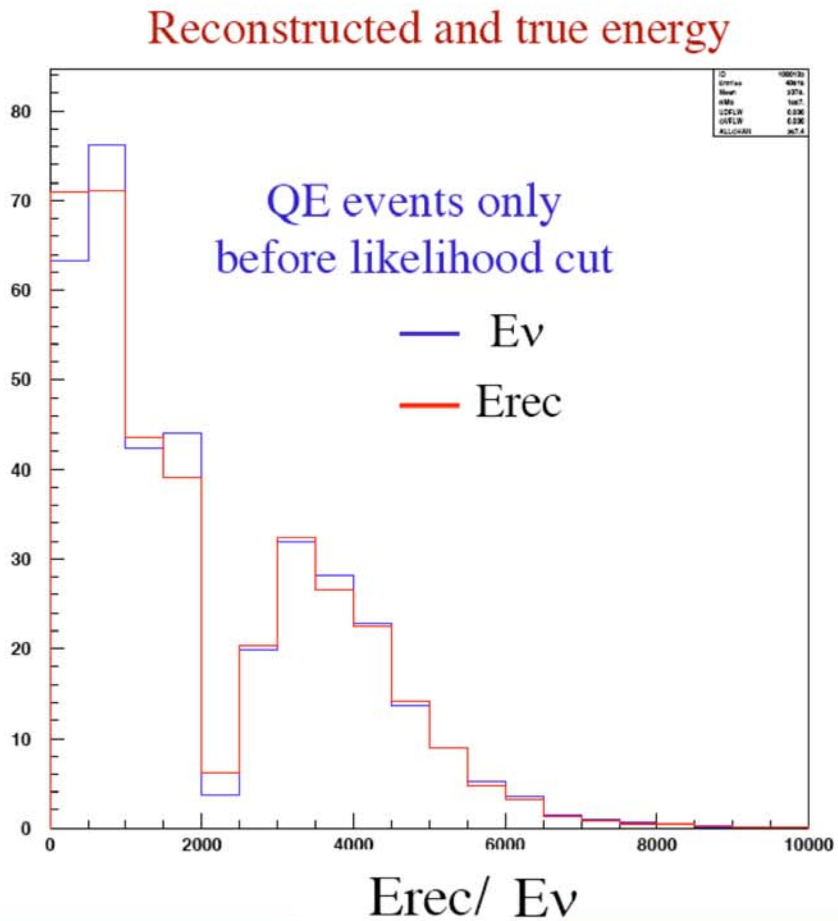
To reduce events with invisible charged pions

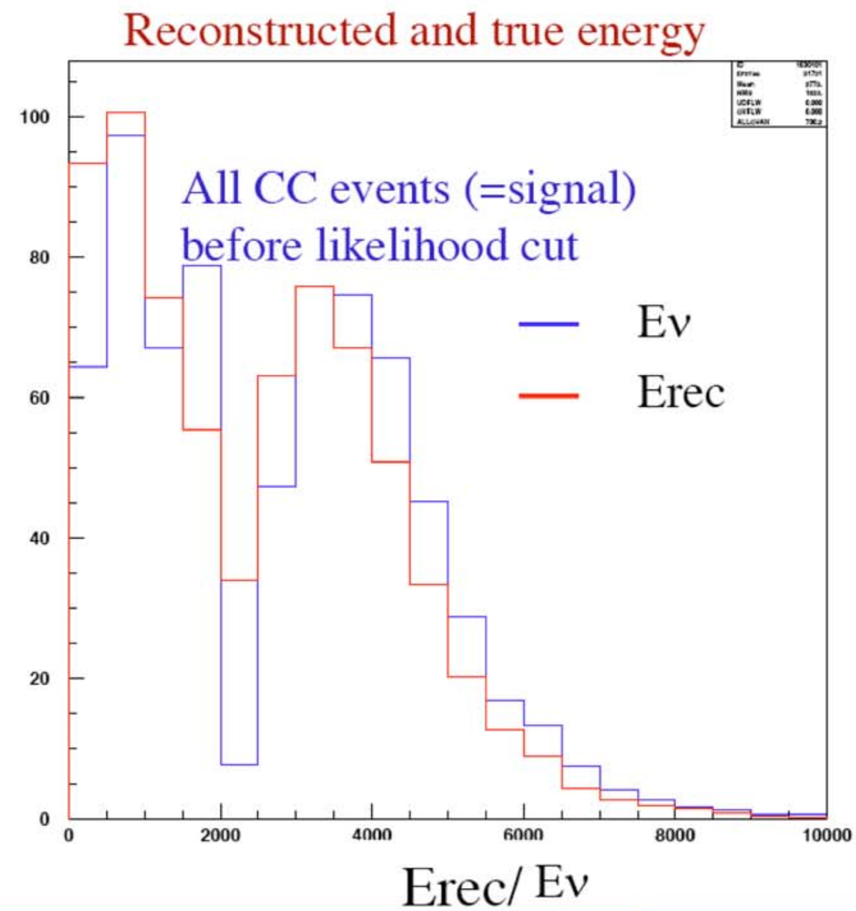
- Likelihood analysis using the following 9 variables: With π^0 finder
  - π^0 mass (pi0mass)
  - energy fraction (efrac)
  - costh
  - π^0-likelihood (pi0-like)
  - e-likelihood (e-like)
  - Δ log π^0-likelihood (Δlog pi0like)
  - single ring-ness (dlfct)
  - total charge/electron energy (poa)
  - Cherenkov angle (ange)

Reconstructed of Neutrino Energy

From now on only single e-like events after initial cuts will be used

Oscillation effect on with CPV+45° at 2,540 km



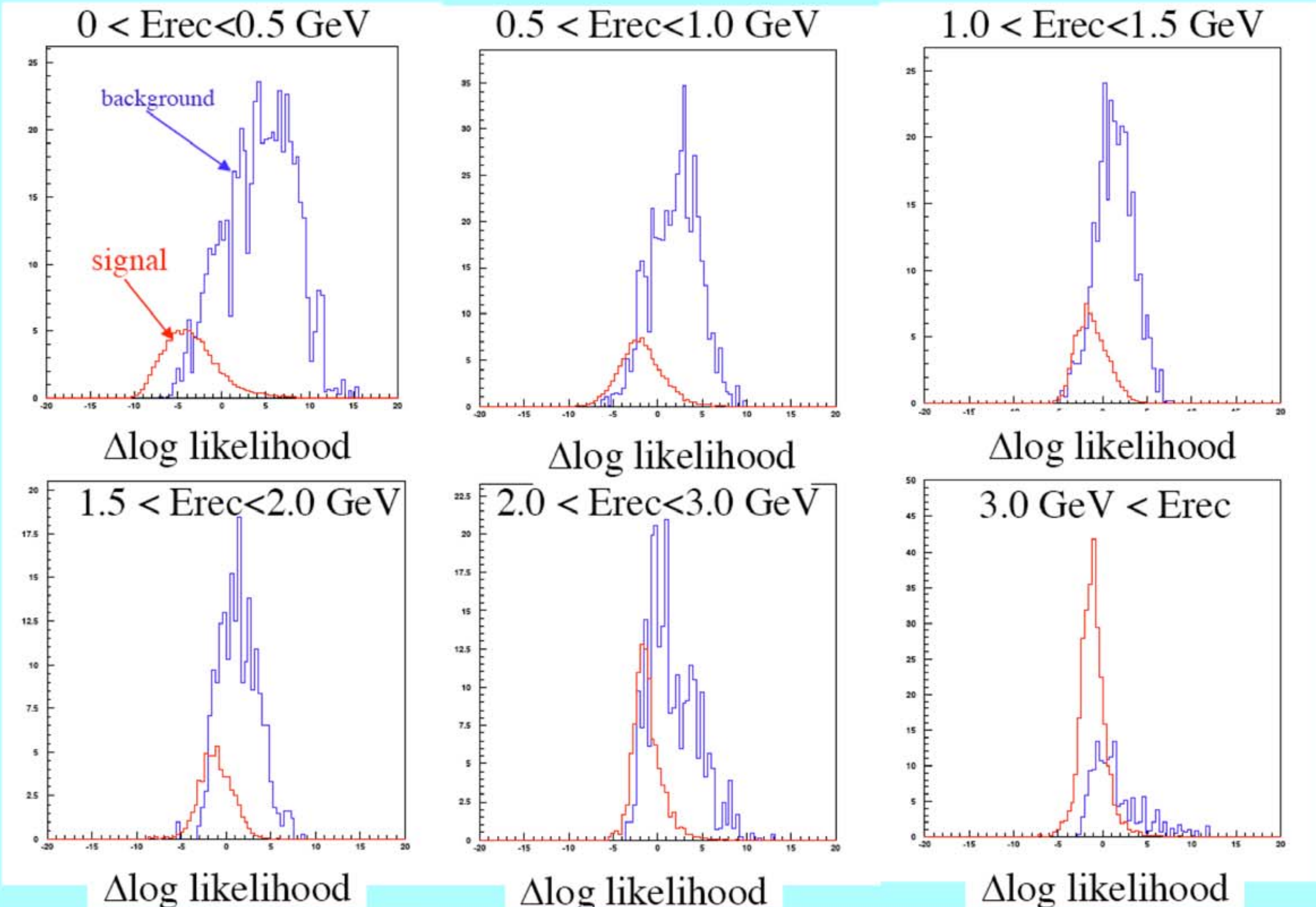


All CC events that survive the initial cuts are signals

Log Likelihood Distributions in Energy Bins

Trained with ν_e CC events for signal, ν_μ CC/NC & $\nu_{e,\tau}$ NC for bkg

- Δ log likelihood distributions log likelihood ratio (signal vs. background)

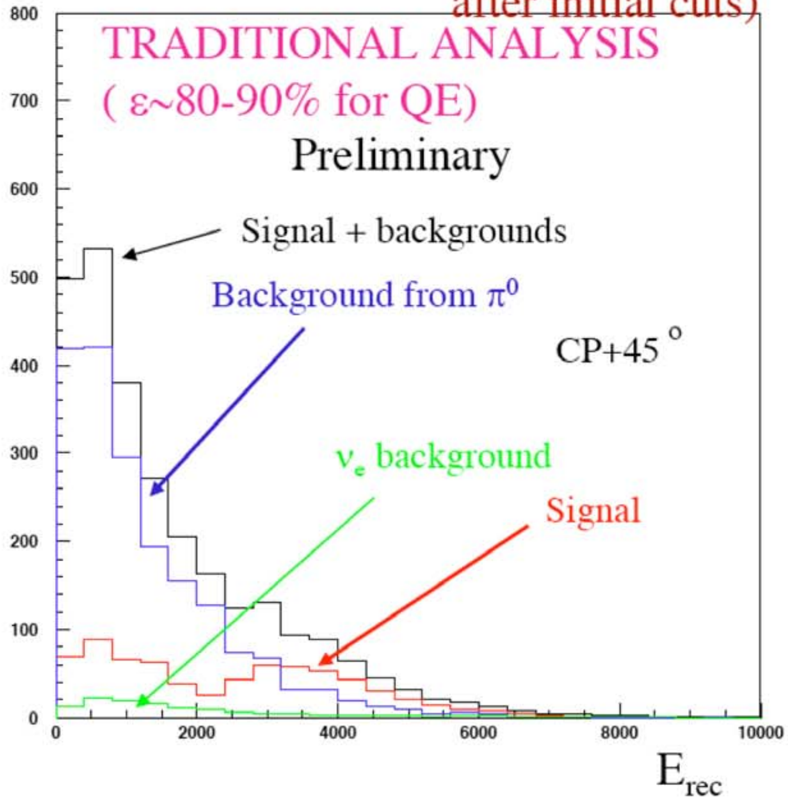


Resulting Effect on Signal/Background BNL-Homestake (2540 km) Case

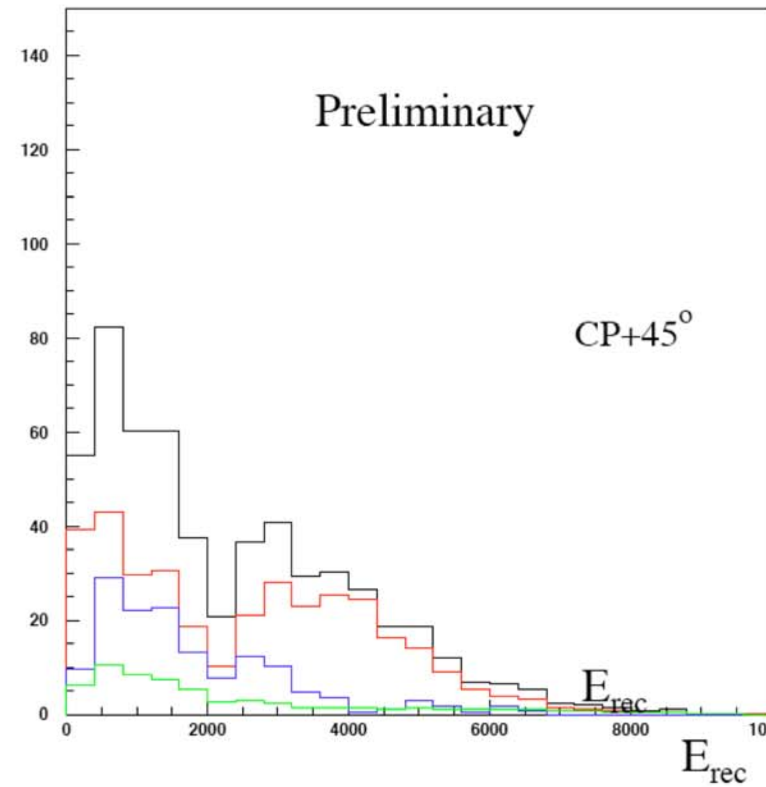
- Effect of cut on Δ log likelihood ν_e CC for signal ; all $\nu_{\mu,\tau,e}$ NC , ν_e beam for background

After initial cuts

No Δ log likelihood cut (100% signal retained after initial cuts)



Δ log likelihood cut (~50% signal retained)

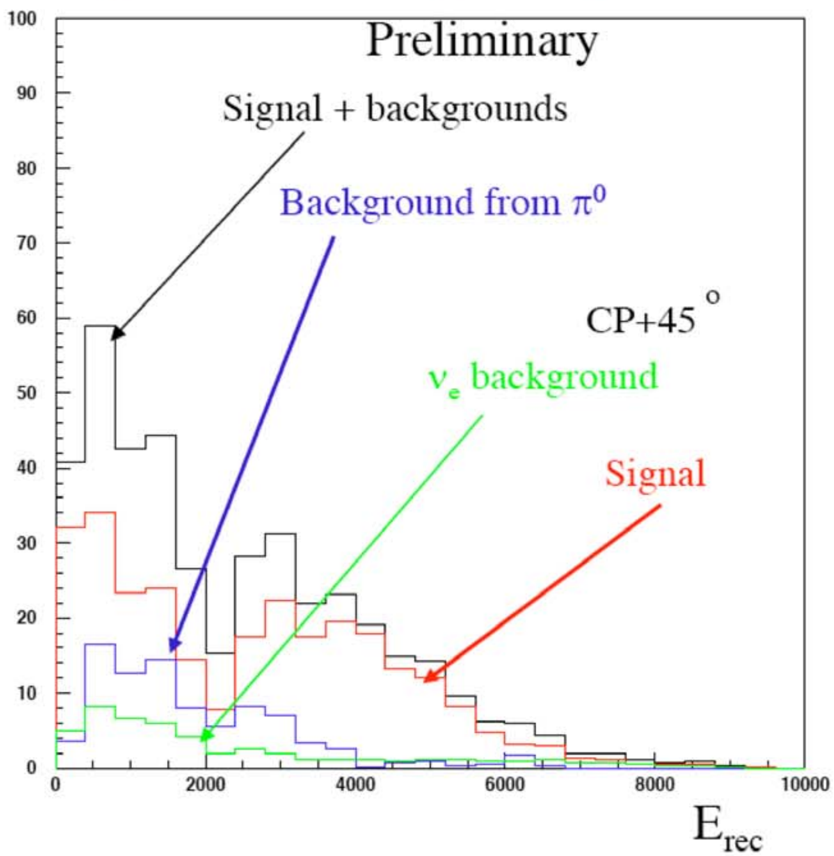


Signal 700 ev Bkgs 2004
(1877 from π^0+others)
(127 from ν_e)

Signal 350 ev Bkgs 169
(147 from π^0+others)
(61 from ν_e)

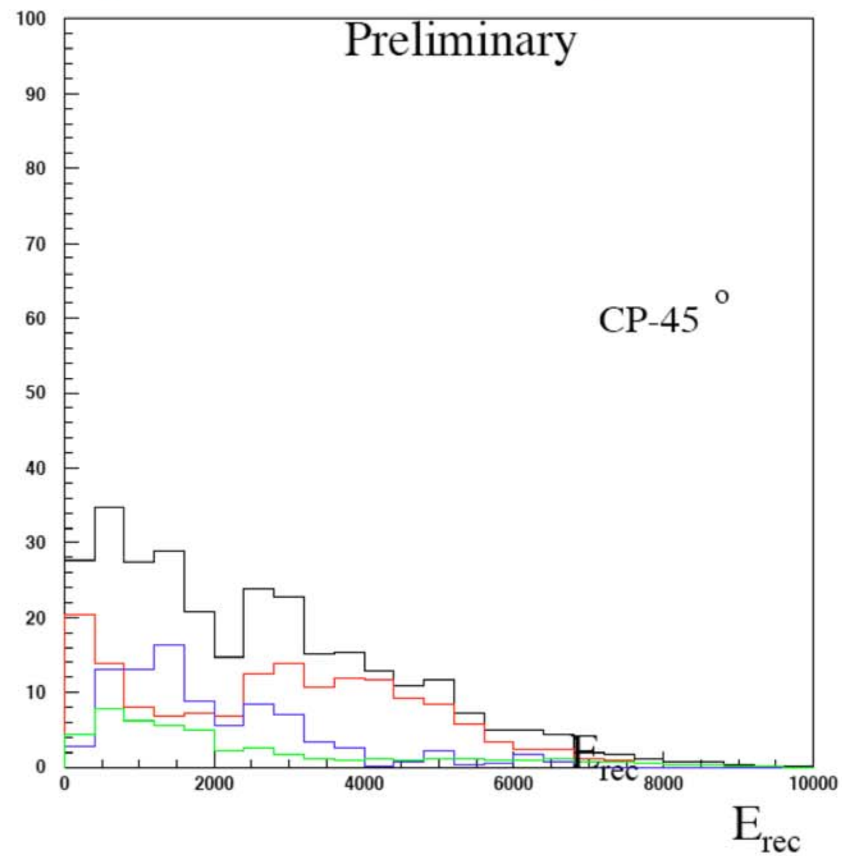
Resulting Effect on Signal/Background BNL-Homestake (2540 km) Case

Δ log likelihood cut (40% signal retained)



Signal 280 ev Bkgs 136
(87 from π^0+others)
(49 from ν_e)

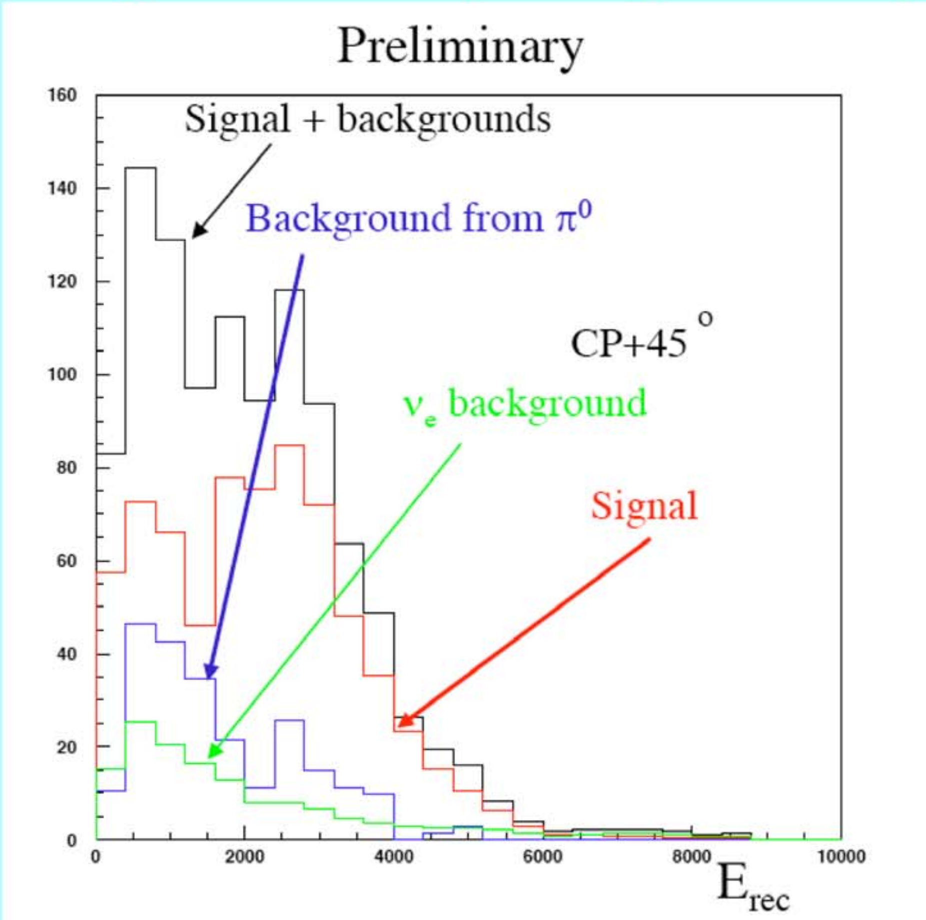
Δ log likelihood cut (~40% signal retained)



Signal 158 ev Bkgs 135
(87 from π^0+others)
(48 from ν_e)

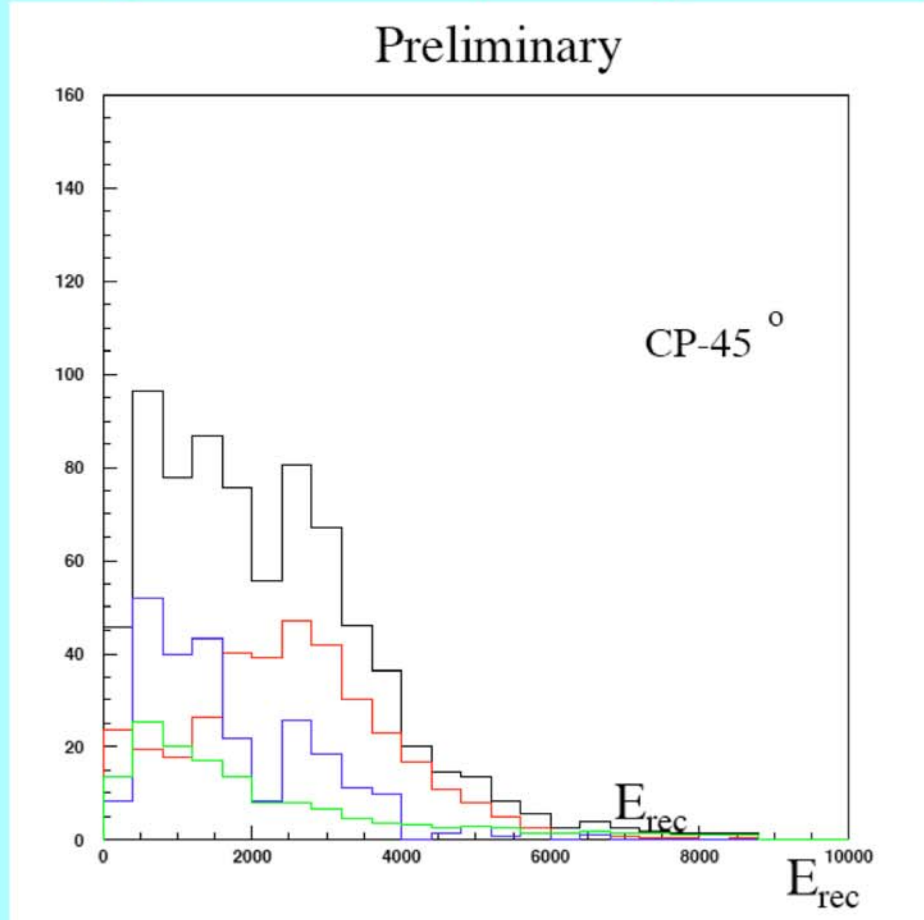
Resulting Effect on Signal/Background FNAL-Henderson (1480 km) Case

Δ log likelihood cut (40% signal retained)



Signal 699 ev Bkgs 373
(233 from π^0+others)
(141 from ν_e)

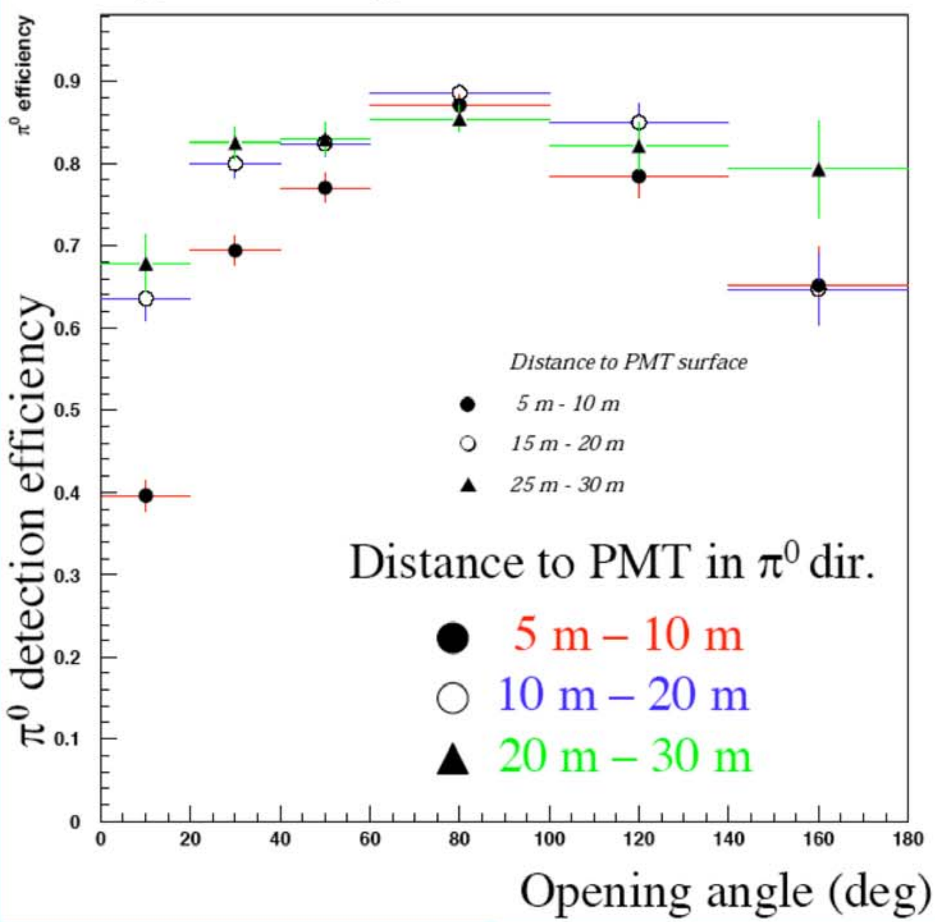
Δ log likelihood cut (~40% signal retained)



Signal 357 ev Bkgs 389
(247 from π^0+others)
(142 from ν_e)

Detector Effective Granularity and π^0 Detection Efficiency

Expected improvement with UNO?



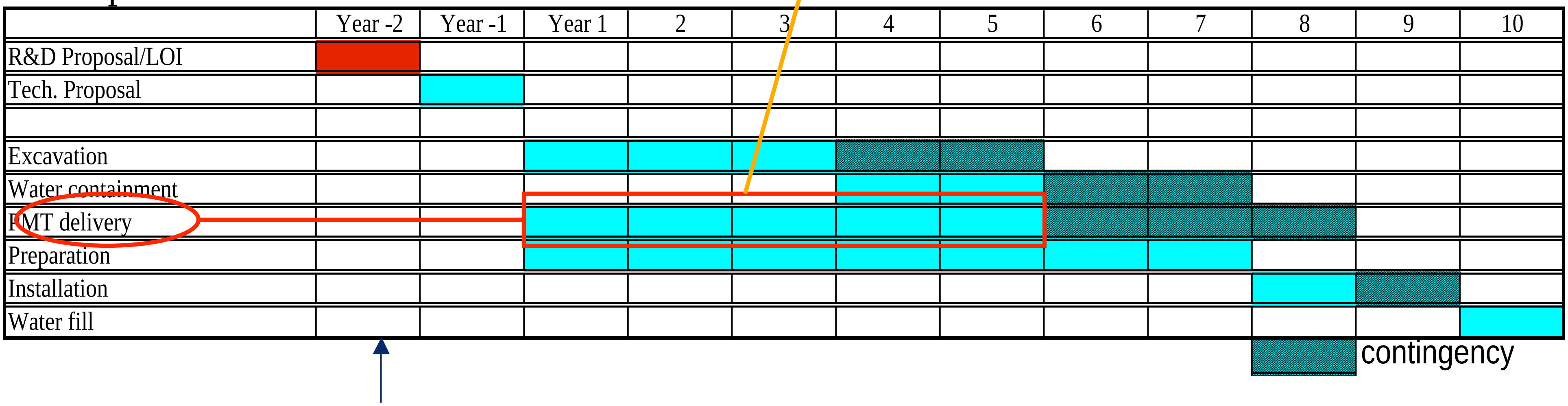
Compared with a smaller detector

- π^0 efficiency improves when distance to PMT in π^0 dir. increases.
- For smaller π^0 opening angle finer granularity is desirable.
- For given PMT size and coverage a larger detector is desirable.

Conceptual UNO Schedule

At LIGHT06 (01/06) claim that Hamamatsu can have possibility for 100,000 PMT production in 2-3 years

Conceptual UNO Schedule



Two years of rigorous professional detector design needed

Very Preliminary Cost Estimate

- Estimates based on scaling SuperK actual costs ($1 = 100 yen)
- Excavation cost quite site dependent
  - if built at existing DUSEL site excavation/access may be reduced to ~$100M
- Existing surface facilities reduce cost
- Better costing estimate will require more detailed detector design
  - collaboration has resisted the urge to update this coarse estimate until we have the resources to do a thorough job
  - For now, we assume it is ~$500M

Item	SuperK	UNO
Cavity Excavation & access [1]	27,640	168,000
Cavity Treatment/Water Tank	18,400	25,000
Water Piping and Pumps	630	4,082
Water Purification System	1,850	11,988
Crane	760	2,280
PMT Support Structure	4,580	23,019
Counting Room	330	990
Instrumentation		
20" PMT (including cables)	34,670	155,457
Electronics	6,330	9,495
DAQ	1,090	1,635
Air Conditioning	210	315
Veto Instrumentation	3,000	9,000
8" PMT (including cables)	2,262	17,881
Surface Facilities [2]		
Computer Building	1,860	2,232
Main Building	3,000	3,600
Power Station	720	2,160
Total	107,332	437,134

Conclusions

- Proton decays provide unique signature for Unification Physics
  - Perhaps the only direct probe of the Unification Scale (~10^{16} GeV)
- Experimental search for proton decays resulted so far no evidence, but set stringent limits
  - Many theoretical models ruled out
- However, large detectors inspired by the GUT models and built for proton decay searches resulted in major discoveries
  - Lesson learned: if we make good instrument, good things can happen
  - Unexpected discoveries are often more revolutionary than the expected
  - Importance of theorists role in realization of an experiment

    Observation of neutrino oscillations (mass)

    Observation of neutrinos from SN1987A

    First real time and directional observation of solar neutrinos

    Confirmation of the solar neutrino flux deficit

Continue: Conclusions

- UNO tackles some of the most important physics questions today w/ potential of major discoveries
- An excellent site exists at the Henderson mine (Homestake)
  - NSF's DUSEL process progressing well
- If built, it will provide a comprehensive nucleon decay and neutrino physics program for the US and world science community for the 21th century
- Intersection of interests from HEP, NP and AP communities; and international community (Japan: Hyper-Kamiokande, Europe: CERN/Fréjus (133 km) initiatives)
- We are one step closer to a realization of the Einstein's dream of unifying all known forces with the discovery of the neutrino oscillations. Hopefully more forward steps can be taken in the near future with major new discoveries.

The End